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A NUMERICAL MODEL FOR SIMULATION OF OIL SPREADING AND TRANSPORT AND ITS APPLICATION FOR PREDICTING OIL SLICK MOVEMENT IN BAYS

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13. ABSTRACT

A computer model for simulating oil spreading and transport has been developed. The model can be utilized as a useful tool in providing advance information and this may guide decisions for an effective response in control and clean-up once an accidental spill occurs.

The spreading motion is simulated according to the physical properties of oil and its characteristics at the air-oil-water interfaces. The transport movement is handled by superimposing the spreading with a drift motion caused by winds and tidal currents. By considering an oil slick as a summation of many elementary patches and applying the principle of superposition, the model is capable of predicting the oil size, shape, and movement as a function of time after a spill originates.

Field experiments using either cardboard markers or soybean oil to simulate a spill were conducted at the Long Beach Harbor. Computer predictions showed good agreement with the field tracers. In order to accommodate the model for use in local port offices, two hardware candidates are proposed.

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FINAL REPORT

A NUMERICAL MODEL FOR SIMULATION OF OIL SPREADING AND TRANSPORT AND ITS APPLICATION FOR PREDICTING OIL SLICK MOVEMENT IN BAYS

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I. INTRODUCTION

The rapid growth of offshore oil production and marine oil transport has led to an increasing danger of oil contamination of the coastal environment. Consequently, there is a growing worldwide concern over possible environmental damage caused by accidental oil spills.

The present study has been aimed at developing a computer model which is capable of predicting oil slick transport in harbors and bays. By means of numerical approximation, the model is able to simulate the spreading and the movement of oil slicks on the ocean surface and to predict their destinations.

The movement of an oil slick is simulated as a combination of the various phenomena which affect the spreading and transport. The simulation of the spreading process is governed by the physical properties of oil and its characteristics at the air-oil and oil-water interfaces. The spreading motion is then superimposed on the drift motion caused by winds and tidal currents to give the total movement. By considering the slick as a summation of many elementary patches in its numerical scheme and applying the principle of superposition to each individual patch, the model is capable of simulating the slick's shape distortion as a result of the relative shear motion produced by the non-uniformity of tidal currents and wind drifts on the water surface.

Sample computations have been conducted using the Long Beach Harbor-San Pedro Bay area as a test case. Several field tests using either cardboard markers or soybean oil to simulate a spill were also conducted in this area. Computer predictions using input obtained from field information show good agreement with the field traces and the validity of the computer model for field operation is substantially confirmed.

In order to accommodate the computer model for use in local port offices, a dedicated small computer system and an alternate time-sharing system are proposed. In either case, the geographical data and the oceanographic environment of a harbor can be pre-fed into the system.

Wind information may be fed constantly to the system from remote sensors in the field. In the event of an accidental spill occurring in this area, one may press a keyboard to supply very simple data such as the time of the spill, type of oil, location and volume of the spill, and from this input the model will predict the oil size, shape, and movement as a function of time. The model may provide a moment-to-moment update of critical conditions. The model may predict the arrival time of the oil slick at various portions of the shoreline along with its spreading and transport well ahead of the true slick's arrival. This advance information of arrival time, location, and size would be extremely useful in guiding the decisions of engineers and operational personnel for an effective response in control and cleanup, and therefore, the model can be a very effective tool to minimize the environmental impact on shorelines as well as on the water quality in harbors.

II. OIL SPREADING ON CALM WATER SURFACE

Oil spills generally occur in two forms. They can be in the form of a continuous release with a time-dependent spill rate such as that which occurred in the Santa Barbara Channel as a result of terminal failure, or they can be in the form of a nearly sudden release such as which may occur as a result of a marine accident of oil carriers. The distinction between the two is mainly dominated by the volume of the spill involved. The failure of an oil drilling terminal naturally involves a large volume and long time and should be characterized as a continuous spill. On the other hand, a relatively small volume spill due to an accidental dumping, which although can hardly complete instantaneously, may generally be regarded as a sudden release.

In this report, only a sudden release of oil is considered. The site of spill is considered inside a harbor or inside the breakwater protection of a bay where the effect of the waves are generally negligible and the water may be regarded as calm.

The basic mechanism affecting the spreading of oil slicks over calm water includes inertia, gravity, viscosity and surface tension. At the initial stage, the primary driving force is due to gravity and the rate of spreading is governed by a balance between the gravitational pressure and the oil inertia. As the spreading proceeds, the oil slick becomes thinner and the viscous effect becomes more evident. Quickly, the oil thickness becomes thin enough so that the inertia effect becomes negligible and the spreading enters into its second phase while the gravitational spreading force is primarily balanced by the water's viscous retarding. The gravity oriented body force gradually becomes less important as compared to the air-water-oil interfacial effect when the film thickness becomes even thinner, typically on the order of milimeters. Finally, surface tension becomes dominant as the major driving mechanism and responsible for the final phase of spreading. The spreading rate at this phase is therefore determined by a balance between the surface tension spreading force and the viscous drag.

By balancing the various combination of forces, Fay [1] derived the governing equations for various regimes. The actual spreading processes at various regimes were also investigated experimentally and results were compared with analytical predictions (Hoult [2]). While the experiments show that the theory predicts correctly in terms of the functional relationship among the governing parameters, discrepancies exist on the magnitude of the proportionality constants. Waldman et al [3], also recommended their values of these proportionality constants based upon an analytical prediction performed by Fannelop and Waldman [4]. Their values in some cases differ as much as 50% from Fay's recommendation. In the following, the governing equations for radial spreading derived by Fay are summarized. With understanding that large discrepancies exist between theories and experiments, the proportionality constants were chosen mainly based upon fitting of empirical data.

1. Inertial Spreading

$$r = 1.14 \; (g \Delta V)^{1/4} \; t^{1/2} \tag{1}$$

2. Viscous Spreading

$$r = 1.45 \left[\frac{\Delta g \; V^2 \; t^{3/2}}{\nu^{1/2}}\right]^{1/6} \tag{2}$$

3. Surface Tension Spreading

$$r = 2.30 \left[\frac{\sigma^2 \; t^3}{\rho^2 \nu}\right]^{1/4} \tag{3}$$

where

r	=	radius of circular patch of oil
g	=	gravitational constant
Δ	=	$\dfrac{\rho_{water} - \rho_{oil}}{\rho_{water}}$

V = volume of spill

t = time

ν = kinematic viscosity of water

σ = spreading coefficient (net surface tension at air-oil-water interface)

ρ = density

For a small volume spill, only the third phase is of significance as the first two phases last only a very short period in the entire spreading history. For instance of a 10,000-gallon spill, the inertial phase lasts only 20 minutes and the viscous spreading process should complete in 40 minutes. Consequently, Equation (3) alone is sufficient to describe the spreading almost entirely except in the very first hour after the spill starts. Good agreement of Equation (3) with the observed data may show the appropriate choice of the proportionality constant (Figure 1).*

Equation (3) also shows that within the surface tension process, the leading edge of the oil spreading is independent of the volume spilled. There is no question, however, that the final area of the film does depend on the volume of the oil spill. Theoretical determination of the final area would involve the knowledge of various physical properties of oil in water, such as the change of the spreading coefficient, the diffusivity, and the solubility. For practical purpose, however, an overall estimate proposed by Fay [5] is used; the relationship is given as follows:

$$A\,(m^2) = 10^5\,[V(m^3)]^{3/4} \tag{4}$$

The expression seems much over-simplified; it relates with only one single parameter, the spill volume. Nevertheless, it does fit the field data very closely as shown in Figure 2.

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*Figures are given at end of report

Nominal values for the physical properties of water and crude oil are used in the entire study; they are listed as follows:

$$\rho_{water} = 1 \text{ gm/cc} = 1.94 \text{ slug/ft}^3$$

$$\rho_{oil} = 0.95 \text{ gm/cc} = 1.84 \text{ slug/ft}^3$$

$$\nu = 0.012 \text{ cm}^2/\text{sec} = 1.296 \times 10^{-5} \text{ ft}^2/\text{sec}$$

$$\sigma = 9.5 \text{ dynes/cm} = 0.65 \times 10^{-3} \text{ lb/ft}$$

Based upon these nominal values, calculated results showing various regime durations are presented in Figure 3. This figure clearly shows that in small volume spills the surface tension phase is dominant during the entire spreading history.

Calculations of the slick growth for spill volumes of 10^3, 10^4, 10^5, and 10^6 gallons are presented as a function of time in Figure 4. Since the slick size is independent of volume in the surface tension phase of spreading, all patches propagate along the same path line until they reach their final dimensions and cease to spread.

The thickness of the oil slick varies from its center to its edge. The exact thickness distribution of a slick can only be obtained through proper modeling of the spreading dynamics during its growth. In order to give an order of magnitude idea about the slick thickness during the various phases of spreading, however, Figure 5 has been prepared by assuming uniform thickness distribution for all cases at all times. The figure shows the nominal thickness variation as a function of time for the same four spills.

III. OIL TRANSPORT IN HARBOR

The primary factors affecting the movement of an oil slick are winds, tidal currents and waves. In the foregoing discussion on the spreading process, the water surface has been assumed calm without any effect due to water circulation or perturbation. In describing the transport process, the assumption is simply extended that the drifting motion of an oil slick caused by winds, currents and waves can be superimposed on the spreading motion of the slick on calm water as described in the previous section.

The direct drift caused by the wind shear stress over the water surface is generally agreed being on the order of 3% of the over-water wind speed. There is disagreement as to the direction, however. For instance the experiments of Teeson and Schenck [6] and the analysis of Warner, et al [7] suggests that an angular displacement on the surface drift due to the effect of earth rotation must be considered, whereas the analysis of the Torrey Canyon Oil Slick Movement [8] shows good agreement by assuming the oil drift always aligned with the wind direction.

It is anticipated that Coriolis force will affect the course of transport if an oil slick is in movement under a steady wind over a large distance on an open sea. While inside a harbor as opposed to an open sea, the winds are highly local and unsteady in some cases and the Coriolis effect can hardly be developed fully in a short time scale; nevertheless, a partial development of the Coriolis effect may be significantly responsible for oil transport.

The effects of surface waves are generally negligible because of their oscillatory nature which produces little net force affecting the spreading motion. Certainly, nonlinear effects of wave interaction may produce surface drift due to second order mass transport. On the other hand, however, there is a retardation effect caused by waves on surface drifts because of the presence of wind shadow on the lee side

of the wave crest. Schwartzberg [9] found that the enhancement and the retardation in surface drift caused by waves are approximately of the same order of magnitude and cancel each other. The apparent wind drift can factually be regarded as a constant, and no net effect caused by waves needs to be considered.

The magnitude and direction of the tidal current are assumed, in the present work, either calculable or measurable with required accuracy. In the numerical example given in the later part of this report, the tidal currents were calculated as a function of time and space with the tidal stage as the input data.

In summary, the transport process of an oil slick is handled as follows:

1. The effects of wind and current are assumed uncoupled with the spreading dynamics and they are superimposable on the spreading motion of an oil slick on calm water.

2. The effects of waves on surface drift are considered negligible.

3. The tidal currents are obtained from either calculations or measurements. They are input data varying as a function of time and space.

4. The wind induced surface drift is assumed to have a magnitude of 3% of the wind speed. Its angle of deviation from the wind direction is to be provided as a part of the input information; otherwise it is assumed to be aligned in the same direction as the wind.

IV. NUMERICAL SIMULATION

1. Model Set Up

The two-dimensional field of a harbor is constructed by a set of perpendicular grids of equal grid spacings. At each grid point, the field characteristic, ie., land or water, is identified by information fed from input data. Each grid point represents a rectangular area of $\Delta s \times \Delta s$, if Δs is the grid spacing. Whenever the grid point represents water in the field, the local water depth should also be specified. In the two-dimensional field, the tidal current and the wind driven current are each represented by a two-dimensional velocity vector at each grid point. The variation in magnitude and direction of these vectors from one grid point to another signifies the surface current distributions. Similarly, if there were oil slicks in the field, the local film thickness (averaging over a Δs square) will be specified at the corresponding grid points.

2. Simulation of Oil Spreading and Transport

The spreading of an oil slick consists of three distinct phases as discussed in Section II. The relationships governing the spreading phenomenon in different phases presented in Section II provide the fundamental information of circular spreading for an oil slick on a calm water surface. When the oil slick is on water of uniform current, the effect of the water movement may simply be superimposed to the spreading motion. When the film is subject to non-uniform disturbances resulting from tide, wind and others, the slick shape would be distorted and appear irregular. To solve the exact problem concerning spreading and transport in an arbitrary velocity field requires a detail analysis of forces on elementary slick segments. The analysis would very likely result in a set of differential equations similar to the convective

diffusion type equations with a tensor of air-oil-water interface spreading, equivalent to a tensor of turbulent mixing relating mass transfer between streamlines in the pollutant transport problem. Assuming that this spreading coefficient could be specified as a function of space and time, there should be no difficulty in general to write a computer program to determine the movement and spreading of an oil slick in a given environment as well as the slick thickness distribution as a function of space and time. Nevertheless, even with modern computers such an attempt would be too expensive to be practical in terms of computing time, if not just ambitious.

Instead of solving the exact problem, the present model simulates the spreading and transport phenomena numerically by means of superposition. The oil film is fictitiously divided into patches according to the already established two-dimensional grids; each patch occupies an area of Δs square centered at the grid point. The concept is to follow the motion of the center of these patches and to superimpose their motion together with a spreading. The process is carried out in appropriate time intervals. At the end of each time step, the average thickness of each patch is obtained by summing up the overlapping layers, resulting from spreading and transport at each grid point.

While the detailed thickness distribution is not exactly material in the present study, the development of the slick size must be correctly simulated. It has been discussed in the foregoing sections that the slick size as well as the regime of spreading depends upon the total volume of oil and the total time elapsed from the beginning of a spill. Instead of following the total volume of the oil, the present scheme focuses its attention on the patches at each grid point. In fact, the adopted concept considers that each patch spreads under the influence of its own volume. At the end of each time interval, new patches of new volume content are to be established, and each new patch spreads accordingly

with its new volume in the next time interval. Following this concept, at the beginning of each time step, all patches are essentially being considered as new spills without previous spreading history and the effective time of spreading for each of these patches therefore counts only from the beginning of the time interval of concern. The concept is similar to that adopted by Fischer [10] in predicting pollutant transport in water. As a result of carrying out this concept, the center of the slick is thicker than elsewhere around initially, but the gradient of the film surface decreases gradually till a limiting thickness governed by the spreading mechanism is reached.

In numerical computations dealing with the diffusion type equations, the time step and grid spacing must be kept in appropriate limits, depending upon the magnitude of the diffusion coefficient, in order to assure the solution to be stable. Similarly, in the present numerical scheme, the correct simulation of the spreading mechanism requires an appropriate choice of the grid size and the time step. The selection of them depends mainly on the spreading coefficient and the spill volume.

It is understood that the inertial and viscous regimes are generally short as compared to the entire spreading history. Since the model is intended to be simple enough for a quick, order of magnitude estimation, in most cases the time interval and the grid space can be chosen in such a way that only the last phase (surface tension)needs to be taken into consideration. Sample calculations for circular spreading of three spill volumes, 1000, 10,000 and 100,000 gallons, are shown in Figures 6, 7 and 8, respectively. Each figure shows a series of the results calculated at a selected time interval. The capability of correct simulation of the slick size during the process of spreading is clearly demonstrated.

3. Model Operating Requirements

The complete computer program is listed in Appendix B. In the following, the input information required by the program is outlined.

The program is designed for predicting oil slick movement in a harbor or nearshore area. The primary input, therefore, is the information of the land boundaries. Land and water are identified by different code numbers. Wherever the region is identified as water, a water depth must also be specified. For a given bay area the above mentioned data are constant and seldom changed. It is therefore convenient that these data are stored on a magnetic tape file in a prearranged order.

The tidal current data should be input as a function of time and space. They can be obtained either through numerical computation from a separate tidal program or by compiling the observed information. In the present study, a separate hydrodynamic program is used for current data generation. This program takes the same boundary specification as the oil slick movement model. It requires the temporal information of the tidal stage as input. The current magnitude and direction are computed for every half hour interval and given as a function of location. These data are stored on a magnetic tape in a prescribed order and chronological sequence.

Other information, such as the site of spill, the quantity of spill, the oil properties, the wind speed and direction, etc., varies from case to case. They must be updated each time the program is operated.

V. AN EXAMPLE PROBLEM

This section presents a complete worked example of computation of oil slick transport using Long Beach Harbor as a sample location. Figure 9 shows a map of the San Pedro Bay area. Figure 10 shows the grid-point mesh established for the bay and the water depth at each grid point. The selected grid spacing is 1000 ft and the asterisks stand for land or ocean boundaries. A typical diurnal tide used for this study is shown in Figure 11; the elevations are with reference to a datum of mean lower low water.

Numerical experiments were conducted in the system to simulate spreading and transport for a sudden release of 100,000 gallons of oil at a location corresponding to grid point N = 12 and M = 16. Three experiments were conducted; in one, only the tidal current was responsible for the oil transport, while in the other two cases additional effects due to wind blowing were imposed. In each experiment, the oil release was assumed commencing at the time corresponding hour 0 in the tidal cycle shown in Figure 11. As discussed previously, a 25 hour cycle tidal current was generated external to the system, but stored on a magnetic tape in sequence of every half hour intervals. Figure 12 shows a series of plots of the current velocity vectors in the bay calculated at several selected reference hours. Similarly, Figure 13 shows the plots at the same reference times when a wind of 5 knots blowing from the northwest at 284.5° was imposed.

Each experiment was run for a period of 36 hours with a time step of 6 hours. Figure 14 shows the spill site (12,16). Figure 15 shows a typical output corresponding to 18, 24, 30 and 36 hours after the 100,000 gallon oil is released at the location (12,16) when wind is not taken into account. Figures 16 and 17 show the results for which various wind blows are included. The numbers at each grid point indicate the thickness of the oil film in 10^{-2} mm, averaged over an area of 10^6 ft^2 around that point. The entire grid space under these numerals indicate the area

covered by oil on the water surface at a particular time. The slick movement seems extremely sensitive to wind in the particular case of San Pedro Bay; this is mainly due to the fact that the tidal currents in this area are generally small.

VI. FIELD TESTS AND MODEL VERIFICATION

In order to verify the numerical model there were, in total, five field tests and demonstrations conducted at San Pedro Bay. The first two tests were made with 3' x 3' cardboards to simulate the oil transport. In the last three tests, soy bean oil was dumped at various locations. These tests covered a wide range of wind speed and direction and they were conducted at various stages with regard to tidal circulations.

1. TEST 1, October 5, 1973

On October 5, 1973 the wind was principally from the southern direction over the area of San Pedro Bay. Three 3' x 3', 1/16" thick posterboard markers were launched at noon time in the southern part of the bay inside the middle breakwater. The cardboards were sealed with paraffin on their edges in order to prevent them soaking between the layers, and were painted with florescent paint of a bright red-orange color. Each board was identified by a number painted in black. The three cardboards were launched approximately 1000 ft. apart from each other from a 25-ft Bertram class motor boat, which has a fiberglass hull and wooden deck finishing. The cardboard markers behaved extremely well on the water surface; they were flexible and moved harmonically with the surface waves. The positions of the markers were fixed by a Cubic Autotape DM-40 electronic positioning system. The system includes a two-range interrogator on board the boat and two responders at fixed locations on shore. The Autotape empbys microwave to measure the ranges between the moving boat and the two fixed sites where the two responders were located. The interrogator visually displays these ranges once per second in 5 metric units. These ranges were also simultaneously recorded on a paper printer.

In the October 5th test, one responder was put at the east end of Terminal Island and the second one was at Pier F of the Long Beach Harbor. The exact locations are shown as A and B in Figure 18.

During the test, the locations of the markers were traced and the distances of each marker from the two responders were recorded as a function of time (Table I)*. The paths of the markers were then determined by fixing their positions using two range lines and the results, a total of about a four-hour tracing, are shown here in Figure 18. Because Marker 2 was generally following the same path as Marker 3, Marker 2 was relocated to a new location at 2:15 PM.

Wind information was obtained by means of an anemometer and a magnetic compass on shore where the responder B was located. Wind speed and direction were recorded every 15 minutes; the records are shown in Figure 19. The tidal stage variation during the whole day may be found in Table II. Taking wind speed as a constant of 8 knots but updating the wind direction every half hour, the routes of the three markers were calculated and compared with the field traces as shown in Figure 20. The computation used a 500 ft grid space and a one hour time step. The total simulation time was four hours for Markers 1 and 3, and two hours for Marker 2 beginning at the relocated position. The computation considered zero angle deflection with regard to the wind drift current. The agreement of the calculated results with the field data appears to suggest that the markers were essentially moving along the direction of the wind.

2. TEST 2, October 10, 1973

This was the second test to use cardboards to simulate oil movements in order to check the credibility of the numerical model. The set-up and the instruments were the same as those for the first test conducted on October 5th, except that the wind information was read on the boat this time. Wind speed and direction were read by means of an anemometer and a magnetic compass. The compass was checked against and in agreement with the magnetic compass on board the boat. The prevailing wind in the early part of the test was south-southwest; it turned to a southwester in the later part of the test. Wind speed and direction were recorded every 15 minutes while the boat made a full stop and the records are shown in Figure 22.

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*Tables are given at end of report

Four cardboard markers were launched inside the middle breakwater at approximately noon time. The four markers were placed at approximately 1000 ft apart to simulate a long slick of about 3000 ft in length. The launching points and the results of a continuous trace of four hours are shown in Figure 21. The ranges of these markers from the two responders A and B are given in Table III as a function of time. Taking Marker 1 as the head and Marker 4 as the tail of a slick, the numerical model computed a four hour movement of the slick. The results are compared with the field data and show fairly good agreement (Figure 23). The computation again used a 500 ft grid space and a one hour time step. The tidal variation for the day may be found in Table II.

3. TEST 3, February 6, 1974

This test as well as the two tests following differed from the previous two tests in two aspects. One, real oil (soybean oil) instead of cardboard markers was used in the field. Two, the previous two tests were essentially to show the credibility of the model for analysis using field information; this test and the two tests following, however, were to show the capability of the model for forecasting with the initial information and the capability of updating when better information becomes available.

There was a northeast wind over the San Pedro Bay area during most of the day on February 6th. The wind was very strong in the morning; the highest reading was up to 30 knots. It became relatively calm in the afternoon and the wind speed was 10 knots at the time when oil was dumped.

Instead of using the Cubic Autotape, a Motorola Mini-Ranger System was used for oil slick positioning. Four responders (or transponders) were stationed onshore; they were identified as A, B, C, and D as shown in Figure 24. The oil dumping and position fixing group was on a Coast Guard 40-ft steel-hull cutter. The

forecasting group was stationed onshore and equipped with a portable teleprinter linked to the Control Data Kronos Time-Sharing System by means of a regular telephone line.

Five gallons of soybean oil were dumped at 1:33 PM. The dumping site and the initial wind condition were transmitted from boat to shore through walkie-talkie type radio communication. The shore group immediately fed these data into the computer and obtained a three-hour prediction. The boat group continued tracing the slick until the wind stopped blowing at 2:29 PM. The recorded ranges from the transponders are given in Table IV and the field trace is shown in Figure 24. The predicted results and the field trace are shown together in Figure 25. The computation again adopted a 500 ft grid space and a one-hour time step; no angular deflection with regard to the wind drift was considered. The agreement was excellent; the only drawback was that the field trace was too short to compare.

4. TEST 4, February 11, 1974

This was the second field experiment using soybean oil to test the prediction capability of the numerical model. The prevailing wind was south-southwest. Soybean oil was dumped at 12:15 PM inside the west end of the middle breakwater close to the Los Angeles Harbor Main Channel. Because of its closeness to the main channel traffic, the slick was unfortunately disturbed by a passing ship, supertanker ESSO BERLIN, and no accurate trace could possibly be made. Despite this unsuccessful start, a second dumping was made at a new location at 2:13 PM. Based upon the information obtained at this location, the shore group predicted the slick movement for two hours. The later field traces are shown in Figure 26; the Mini-Ranger readings and the wind information are given in Table V. The predicted results together with the field trace are shown in Figure 27.

The tidal stage variation on February 11th is given in Table II. It is clear that at 2:13 PM the water in the bay was close to slack, and the dominant driving force was due to wind drift. The predicted results were obtained based upon the information received at 2:13 PM; the wind speed was 9 knots and the direction was 215° (magnetic). As shown in Figure 26, however, the field traces were approximately along the direction of 230° - 235° (magnetic). The discrepancy was approximately 15 - 20 degrees.

The discrepancy was considered possibly due to two uncertainties; (1) the accuracy of the compass, and (2) the wind drift deflection. As with many Coast Guard small boats, the one used on February 11th was not equipped with a compass. A hand carried magnetic compass was used for wind direction readings; however, no error deviation of the compass was checked. As to the wind drift, although the October 1973 tests seemingly showed no deflection effect on the cardboards, it was suspected that an oil slick may behave the same as cardboards.

In order to clear doubts and to answer the above questions, one more test was scheduled on the following day.

5. TEST 5, February 12, 1974

The wind condition was very similar to the previous day. The wind direction was read from the magnetic compass in the same way as done previously. In order to determine the compass deviation error on the boat, wind direction relative to a bearing of a fixed known physical object, the Los Angeles Lighthouse (where the transponder C was located), was also recorded; from this information the correct wind direction in a magnetic reading could be computed. Wind directions obtained by this method and wind directions directly read from the magnetic compass are both given in Table VI. Comparing the data obtained by these two methods, one may find that on the boat the magnetic compass had a westerly deviation of approximately 10 degrees.

Five gallons of soybean oil were dumped at 3:27 PM. The initial wind speed was 9.5 knots and the correct wind direction was 220° (magnetic). Prediction based upon this information again showed an approximately 10 degree discrepancy with the traced data obtained later on. It appeared that a 10 degree wind drift deflection had to be included in the computation for better agreement. A complete three-hour trace of the oil slick was made; the results are plotted in Figure 28. The predicted oil movement together with the field traces are shown in Figure 29.

In summary, the February 12th test led one to believe that:

(1) The magnetic compass readings recorded in the last three tests had a westerly deviation of 10 degrees approximately;

(2) There was approximately a 10 degree clockwise deflection on wind induced drift.

Including the above considerations, a new prediction of the February 11th test was made; Figure 30 shows the predicted results in good agreement with the field traces.

VII. HARDWARE CONSIDERATIONS

1. Dedicated System

The desirability of local operation of the present oil spreading and transport program prompts consideration of accommodating the program for execution on a dedicated, small computer. Questions necessarily raised thereby involve computational accuracy, execution speed, and core size limitations. While there is no foreseen difficulty to overcome these problems in warranting consideration of a small computer configuration, considerable converting effort for the present program would be required to adopt such a large program to a small machine of limited storage. In the following a proposed hardware configuration is first outlined, and then certain conversion problems are discussed.

The proposed computing system and its cost estimate are described in the following table.

Item	Model	Description	Cost
DEC Graphic Unit	GT44-AA		$34,500
- 16K Processor		PDP-11/40 Central Processor	
- Scope Display		17"CRT Monitor w/Light Pen	
- Disk Unit		1.2 Megaword Disk Drive and Control	
- Printer		30 cps DEC Writer	
16K Sense Memory	MM 11-U KT 11-D	Extended memory and memory management	7,205
Tape Unit	TM 11-FA	7-Channel Tape	11,385
		TOTAL	$53,090

In the above proposed system, the DEC PDP 11/40 processor is adopted as the baseline machine, around which peripheral equipment consisting of a tape unit, disk, and display devices are structured. It should be noted that the above proposed system is selected only as a most promising example and that it should not be considered the only configuration satisfying the requirements.

The PDP 11/40 is a very sophisticated small computer. Arithmetic operation and memory reference times are approximately equivalent to those of the much larger CDC 6600. A FORTRAN compiler is available for this machine and the DEC assembly language is versatile and straight forward. A magnetic tape unit is included for data handling and a disk unit is for the extension of central memory. An oscilloscope display unit is included for interactive program input/output operations.

Based upon a preliminary analysis, a 32K memory of the 11/40 appears sufficient to contain the current form of the present program if single word integer operations are utilized throughout and the program instruction set can be compacted with no increase in instruction words. In its present form the program uses data arrays at a prescribed grid scale, appropriate to an area equivalent to Long Beach Harbor. If the present grid scale is to be maintained, any area larger than the harbor at Long Beach must require periodic grid displacement to track the slick motion. As the present scheme stands, the program updates the data arrays every half hour of simulation time, corresponding to the update intervals of the tidal current distribution. Each half hour of simulation time, therefore, would initiate a new computational sequence covering another one half hour of simulation time. Converting of the present program would thus require:

(1) Compacting the instruction set, via assembly language, to reach the memory capacity of the small computer

(2) Incorporating integer arithmetic operations throughout the program

(3) Developing the logic to enable the data arrays to follow slick movement over an extended area

(4) Developing the interactive and input/output capability on oscilloscope display appropriate for field application of the program.

2. Time Sharing System

The other candidate for local operation of the numerical model is a time sharing system which permits one to use the large and sophisticated computer, like the CDC 6600, through a linkage of a regular telephone line to his local terminal. This is probably the least expensive way of operation as the only hardware required is a portable terminal including a displaying scope. A software development for interactive capabilities on oscilloscope display is required as in the dedicated system. Since the system allows one to use a large computer, no conversion problem is necessary inasmuch as the available core memory is sufficiently large for the problem under consideration.

VIII. DISCUSSION AND CONCLUSION

The programs presented in this report are an attempt to simulate by means of numerical approximations the movement of oil slicks in a harbor after an accidental oil spill occurs. This section reviews some important approximations, comments on their validity and evaluates the degree to which the program will accurately simulate.

1. Spreading and Transport

The important approximation used herein is the spreading process simulation. The numerical procedure is an attempt to represent the effect of the pressure gradient over the slick boundary of the elementary patches. The concept assumes that each patch of oil slick will locally spread and diffuse over a circular field whose radius is stretched approximately by one grid space during one time step before the final area of the slick is reached. At the end of each time step, a superposition of the overlapping patches takes place. It is obvious that the grid size and the time step are necessarily governed by the spill volume and the spreading characteristics in order that the spreading process is properly simulated. This is equivalent to the grid size and the time step being controlled by the diffusion coefficient in solving convective-diffusion equations by a finite difference technique.

While the necessity of adjusting the grid size and the time step is fundamental for a proper simulation of spreading, the application of the numerical program is not limited by these restrictions. From an operational point of view, the total spreading process is generally too short to be important. In other words, the impact of slick transport is generally more significant than the consequence of spreading in affecting decision on directing protective actions and control. Consequently, the grid size and time step may not necessarily tie up to the type and volume of the oil spill; they may be chosen essentially for convenience. The program then adopts a simple procedure to provide advance information on the slick's area and shape as a function of time.

The adopted concept of superimposing a transport motion on a spreading motion in calm water signifies that the mechanism for spreading and dispersion is essentially isotropic, which is known as not supported by observations. Field observations often find oil slicks pronouncedly stretched in the direction of drift. This phenomenon may be taken into consideration in the numerical scheme by including the directional property in the spreading coefficient, provided that sufficiently reliable data are available in this regard.

Field observations of drift markers and small scale oil slick movements have essentially validated the numerical model. While the present method seems to yield realistic results for slick movement prediction, the more appropriate and accurate way to deal with the problem would be to use a finite difference scheme to solve the diffusion type equation, assuming a new generation of larger, faster computers is available. At present, the current method has at least the following advantages in comparison with the finite difference scheme. First, the spreading step is modeled in a physical way which permits immediate comparison with field observation, so that updating of field results can be easily achieved. Secondly, the present program is computationally fast which is not only important for quick decision on directing control and cleaning but substantial costs can be saved.

2. Sensitivity to Parameter Update

The present model considers two primary driving mechanisms which are responsible for the transport of an oil slick: they are winds and currents. The currents in San Pedro Bay are generally small. The maximum currents inside the bay are generally on the order of 0.2 ft/sec. They are higher along the two harbor channels, but generally not higher than 0.5 ft/sec. On the other hand, the winds over this area are rather non-uniform and unsteady. As a result, a correct prediction of slick movements highly depends on how good the available wind information is. The computation is especially sensitive to the accuracy of the information on wind directions.

The model is capable of being updated with new information every half hour. The updating may include any or all of the following: slick position, wind speed, wind direction, and current distributions. Practically speaking, with a frequency of half hour updating, the maximum projection error in slick position would in no case be greater than one grid space. Theoretically, the resolution depends upon both the grid size and the total drift rate. Taking San Pedro Bay as an example, assume that the grid spacing is 1000 ft, the tidal currents are negligible and the average wind speed is 10 knots. Assume further that the speed variation of wind in a short time scale, for instance a few hours, would not exceed $\pm$ 10% and its direction variation would not exceed $\pm$ 10 degrees. The average drift rate in this case is approximately 0.5ft/sec and an updating every three hours would keep the projection error within one grid space.

3. Model Operating Guidelines

The fact that the computation of the model is highly sensitive to wind information has been discussed in the foregoing paragraph. In some harbors tidal circulation may be of the same order of magnitude as the wind drift; then, accurate time and spatial information on tidal current variations is also vital for an accurate prediction. The third factor which may affect the prediction is the information on the angular deflection of the wind induced drift from the over-surface wind direction. In order to accommodate the model to a harbor for an accurate simulation, matters with regard to accurately providing or collecting the above three items must be taken into consideration.

Winds are known as the most sensitive input in executing the present program. To assure that accurate, temporal wind information is available to the computer, a number of remote sensors should be established in the field. These sensors may continuously provide wind speed and direction information at various locations and an interpolation of these data can be made available to the computer at any time. The number of sensors required is mainly dependent on the degree of uniformity of wind over the harbor. A survey by taking simultaneous recordings of winds at several stations around the harbor can be easily conducted to determine their distribution pattern from which the number and location of sensors needed may be determined.

Tidal currents are less critical than winds as the current distributions roughly have a fixed pattern which repeats periodically. Problems which need to be taken into consideration are those involving systematically taking temporal and spatial measurements. Field measurements require substantial undertaking in terms of both labor and time. Computation using a hydrodynamic model is probably a better approach in most cases as it generally provides better and more detailed information than field data if the field data are not thorough and complete.

It is anticipated that the Coriolis force may play an important role in altering the course of an oil slick if it is transported over a long distance. Inside a harbor over a short time span, however, one should expect the wind drift deflection to be negligible. Nevertheless, the field test of soybean oil in San Pedro Bay showed an approximately 10 degree clockwise deflection in wind induced drift. There are no sufficient data available with regard to the wind drift deflection in harbors. Field surveys are necessary to obtain this information.

4. Other Applications

While the numerical model was constructed with the purpose of predicting and tracking oil slick movement in harbors, its application may not be limited to harbors only. The model may equally be valid for deep ocean and estuaries as well, provided that some important considerations are taken into consideration. In the case of deep ocean relatively far away from the coastal shoreline, geostrophic currents may be substituted for the tidal currents in the model to provide good prediction as the tidal excursions are generally taking an elliptical path of small radius on the order of a few miles and produce little net drift in a long run. For application in an estuary where tide meets with water flushed from channels, the complexities involved are to obtain accurate information of current distribution around channel entrances. Current distribution is a function of time and space. Direct measurements in the natural area to determine this information would require tremendous undertaking and cost, and generally are impractical. A hydrodynamic-numerical model requires less effort and is much less expensive, however, most existing models are not suitable for estuary problems. Numerical models applied to oceanographic problems usually consider them two dimensional. Around the channel entrances, however, parameters such as the vertical shear distribution and fluid stratification as well as the bottom and the lateral friction stresses become important and the third dimension effect must not be ignored. In any case, once the accurate current information becomes available, either through numerical computation or field measurement, the present model may be easily adapted for use in estuaries.

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X. ACKNOWLEDGEMENT

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APPENDIX A

Input Data Sequence for Program SLICK

Card No.	Columns	Variable	Description
1 (8A10)	2-80	ID(8)	Problem identification
2	1-5	NMAX2	Dimension of computational grid — column
(4I5)	6-10	MMAX2	Dimension of computational grid — row
	11-15	NIND	Total number of vertical lines required to compose the field points inside the harbor
	16-20	IDX	Grid spacing in feet
3	1-10	Q	Volume of spill in gallons
(3F10.0)	11-20	ROIL	Density of oil in gm/cm^3
	21-30	SIG	Spreading coefficient in dynes/cm
4	1-5	NOY	Column number indicating the spill site
(6I5)	6-10	MOX	Row number indicating the spill site
	11-15	ITIME	Reference time at which computation starts, in hours after spill occurs
	16-20	IMAJ	Tidal stage reference
	21-30	NHOUR	Total number of hours to be computed
5	1-5	IK	0 Current data read from Tape 7
(I5)			1 Zero currents assumed
7	6-10	IOP	-1 Program computes only the slick centroid movement, no spreading mechanism considered

Card No.	Columns	Variable	Description
			1 Both spreading and transport are simulated
	11-15	IT	0 Ordinary input
			1 Updating data required
	16-20	IP	0 Slick thickness in 10^{-3} cm printed in the output
			1 Slick area identified by character "O" in the output
	21-25	NP1	Number of the first column to be printed
	26-30	NP2	Number of the last column to be printed
	31-35	NP3	Maximum number of columns to be printed on each page of the output
6	1-10	WN	Wind speed in knots
(6F10.4)	11-20	DPH	Latitude in degrees at which harbor locates
	21-30	THM	Wind direction in degrees referred to magnetic north
	31-40	THMN	Deviation of magnetic north from true north, positive toward east, degrees
	41-50	THR	Angle between the grid column and the true north, degrees
	51-60	ALF	Deflection angle of wind driven current, degrees (for zero deflection angle, a small number like 0.0001 should be used; a zero input will force the program to calculate the deflection angle at every point according to the Ekman's formula)

Card No.	Columns	Variable	Description
IF IT $\neq$ 0, cards for updating the slick covering area are required			
7	1-4	NDXY	Number of grid points to be updated
(2014)	5-8	NN	Column number of the grid point corresponding to the area covered by oil
	9-12	MM	Row number of the grid point corresponding to the area covered by oil
		(Total NDXY pairs of NN and MM are continuously given in this card and the cards followed)	

APPENDIX B

PROGRAM LISTING

```
      PROGRAM SLICKS(INPUT,OUTPUT,TAPE1,TAPE7)
      COMMON X(900),Y(900),C(900) ,U(900),V(900),KONVERT(900),
     1    IREGION(1100),DEP(1100),UW(900),VW(900),ALPHA(900),UU(900),
     2    VV(900)
      COMMON /NEW/ ID(8),MO,ROIL,IDX
      COMMON /ALL/ IK,IT,IP,MAJOR,ICYCLE,NCYCLE,IMAJ,ITIME,
     *              IDIV,IM,IN
      COMMON /BAY/ NIND,NST,MST,DX,DXH,DXR,NLINE(150),MF(150),ML(150)
      COMMON /OLD/ NP1,NP2,NP3,NP4,NP5
      COMMON /ABC/    NOY,MOX,DRO,SIG,VCM
      COMMON /EGH/ COM  ,NP,NINT,IOP
      DATA ICYCLE,INDXPRT/1,1/
      DATA IDIV,IN,IM,NBMX,MBMX/1,1,1,0,0/
      READ 77,ID
   77 FORMAT(8A10)
      READ 50, NMAX2,MMAX2,NIND,IDX
   50 FORMAT(10I5)
      IF(NBMX.EQ.0) NBMX=NMAX2
      IF(MBMX.EQ.0) MBMX=MMAX2
      READ 51, Q,ROIL,SIG
   51 FORMAT(8F10.0)
      READ 50, NOY,MOX,ITIME,IMAJ,NINT,NHOUR
      READ 50, IK,IOP,IT,IP,NP1,NP2,NP3
      COM=0.
      NP5=1
      NCYCLE=NHOUR/NINT
      MAJOR=0
      RO=1.
      DRO=(RO-ROIL)/RO
      MO=0
      VCM=Q*3790.
      DX=IDX
      DXH=0.5*DX
      DXR=1./DX
      NR1=NMAX2+4
      MR1=MMAX2+4
      CALL ENVIRON (C,Y,X,KONVERT,U,V,NMAX2,MMAX2,IREGION,NR1,MR1,
     *           DEP,UW,VW,ALPHA,UU,VV,NBMX,MBMX)
      CALL EXIT
      END
```

```
      SUBROUTINE ENVIRON (C,Y,X,KONVERT,U,V,NMAX2,MMAX2,
     1 IREGION,NR1,MR1,DEP,UW,VW,ALPHA,UU,VV,NRMX,MRMX)
      DIMENSION DEP(NMAX2,MMAX2),UW(NMAX2,MMAX2),VW(NMAX2,MMAX2),
     *          ALPHA(NMAX2,MMAX2)
      DIMENSION  C(NMAX2,MMAX2),X(NMAX2,MMAX2),Y(NMAX2,MMAX2)
      DIMENSION U(NMAX2,MMAX2),V(NMAX2,MMAX2)
      DIMENSION UU(NRMX,MRMX),VV(NRMX,MRMX)
      DIMENSION KONVERT(NMAX2,MMAX2),IREGION(NR1,MR1)
      COMMON /NEW/ ID(8),MO,ROIL,IDX
      COMMON /ALL/ IK,IT,IP,MAJOR,ICYCLE,NCYCLE,IMAJ,ITIME,
     *             IDIV,IN,IM
      COMMON /BAY/ NIND,NST,MST,DX,DXH,DXR,NLINE(150),MF(150),ML(150)
      COMMON /OLD/ NP1,NP2,NP3,NP4,NP5
      COMMON /ABC/   NOY,MOY,DRO,SIG,VCM
      COMMON /DEF/ UC(32,26),VC(32,26)
      COMMON /EGH/ CON ,NO,NINT,IOP

      IF(IK-1) 29,30,31
   31 CONTINUE
      DO 20 N=1,NR1
      DO 20 M=1,MR1
   20 IREGION(N,M)=3
      NR13=NR1-3
      MR13=MR1-3
      DO 19 N=4,NR13
      DO 19 M=4,MR13
   19 IREGION(N,M)=1
      NIND=NMAX2-2
      DO 21 N=1,NIND
      NLINE(N)=N+1
      MF(N)=2
   21 ML(N)=MMAX2-1
      GO TO 69
   29 REWIND 7
      READ(7)
      IF(IMAJ.EQ.0) GO TO 30
      DO 28 IA=1,IMAJ
      READ(7)
   28 CONTINUE
   30 REWIND 1
      READ(1)    ((IREGION(N,M),N=1,NR1),M=1,MR1)
      READ(1)    (NLINE(N),MF(N),ML(N),N=1,NIND)
      NLINE(NIND+1)=9999
      READ(1)    ((DEP(N,M),N=1,NMAX2),M=1,MMAX2)
   69 PRINT 70,ID,       IDX,NINT
   70 FORMAT(*1*,8A10,//          * GRID SPACING=*I10* FT,  TIME SPACING=*
     *     I3* HOURS*/)
      PRINT 71, MO
   71 FORMAT(1H0,*  Q=*I10* GALLONS*)
      IF(CON.NE.0.) PRINT 72
   72 FORMAT(1H 16X,*PER HOUR* )
      PRINT 73, ROIL,SIG
   73 FORMAT(1H0,*  DENSITY OF OIL=*F6.2* GM/CC*// *   SPREADING COEFF=*
     1     F6.2 * DYNES/CM* )
```

```
      IF((IF.GT.1) .OR. (NP5.NE.0)) GO TO 90
      PRINT 85
      PRINT 87,(NLINE(N),MF(N),ML(N),N=1,NIND)
 85   FORMAT(*0   N    MF    ML*,/)
  87  FORMAT(3I5)
      PRINT 43, (N,N=1,NR1)
  43  FORMAT (//*1  REGION DESCRIPTION IN CODED ARRAY*//*0 M   N*,40I2)
      DO 44 M=1,MP1
      PRINT45,M,(IREGION(N,M),N=1,NR1)
  45  FORMAT (* *I2,3X,40I2)
  44  CONTINUE
 90   CONTINUE
      DO 50 N=1,NMAX2
      DO 50 M=1,MMAX2
      UC(N,M)=VC(N,M)=0.
  50  C(N,M)    =9999.
      DO 10 NUM=1,NIND
      N=NLINE(NUM)
      MFST=MF(NUM)
      MLST=ML(NUM)
      DO 10 M=MFST,MLST
  10  C(N,M)=0.
      CALL WINDS(KONVERT,NMAX2,MMAX2,IREGION,NR1,MR1,DEP,UW,VW,ALPHA)
      CPO=VCM/(12.*2.54)**3
      MO=VCM/3790.+0.5
      IF(I1)     110,100,110
 110  CALL UPDAT(C,NMAX2,MMAX2,CPO,DX,SCK)
      GO TO 130
 100  IF(CON.NE.0) MO=0
      C(NOY,NOX)=CPO/(DX*DX)
 130  DO 120 M=1,MMAX2
      DO 120 N=1,NMAX2
      KONVERT(N,M)=1000.*C(N,M)    *12.*2.54    +0.5
      IF(KONVERT(N,M).GE.9999) GO TO 120
      ICOR=    KONVERT(N,M)
      IF(ICOR.NE.0) KONVERT(N,M)=-99
 120  CONTINUE
      CALL PRINTC (KONVERT,NMAX2,MMAX2,NP1,NP2,NP3,ITIME,MO,IDIV,IN,IM,
     *            NRMX,MRMX)
      CALL CONC              (C,Y,X,KONVERT,U,V,NMAX2,MMAX2,
     1 IREGION,NR1,MR1,DEP,UW,VW,ALPHA,CPO,UU,VV,NRMX,MRMX)
      RETURN
      END
```

```
      SUBROUTINE WINDS(KONVERT,NMAX2,MMAX2,IREGION,NR1,MR1,DEP,UW,VW,
     *           ALPHA)
      DIMENSION DEP(NMAX2,MMAX2),UW(NMAX2,MMAX2),VW(NMAX2,MMAX2),
     *           ALPHA(NMAX2,MMAX2)
      DIMENSION KONVERT(NMAX2,MMAX2),IREGION(NR1,MR1)
      COMMON /ALL/ IK,II,IP,MAJOR,ICYCLE,NCYCLE,IMAJ,ITIME,
     *             IDIV,IN,IM
      COMMON /BAY/ NIMD,NST,MST,DX,DXH,DXP,NLINE(150),MF(150),ML(150)
      COMMON /OLD/ NP1,NP2,NP3,NP4,NP5
      WN=0.
      DO 50 N=1,NMAX2
      DO 50 M=1,MMAX2
      UW(N,M)=VW(N,M)=0.
   50 CONTINUE
      READ 8180,WN,DPH,THM,THMN,THR,ALF
 8180 FORMAT(8F10.4)
      DTH=THM+THMN
      IF(WN.EQ.0.) GO TO 207
      WFPS=WN*1.689
      PI=3.14159
      THETA=(DTH+THR)*PI/180.
      PHI=DPH*PI/180.
      DO 80 N=1,NMAX2
      DO 80 M=1,MMAX2
      NE=N+2
      ME=M+2
      WIND=WFPS
      IF(IDIV.GT.1) GO TO 73
      IF(IREGION(NE,ME).EQ.2) DEP(N,M)=WIND=0.
   73 IF(IK.GT.1) DEP(N,M)=1000.
      IF(ALF) 74,75,74
   74 ALFA=ALF*PI/180.
      GO TO 5
   75 CONTINUE
      DP=DEP(N,M)
      FD=PI*SQRT(6.7/(64.*7.29E-05*SIN(PHI)))
      ARG=2.*PI*DP/FD
      TANA1=SINH(ARG)-SIN(ARG)
      IF(TANA1.EQ.0.) GO TO 2
      TANA2=SINH(ARG)+SIN(ARG)
      IF(TANA2.EQ.0.) GO TO 3
      ALFA=ATAN2(TANA1,TANA2)
      GO TO 5
    2 ALFA=0.
      GO TO 5
    3 ALFA=PI/2.
    5 CONTINUE
      ALPHA(N,M)=ALFA*180./PI
      UW(N,M)=-0.03*WIND*SIN(1.5*PI-THETA-ALFA)
   80 VW(N,M)= 0.03*WIND*COS(1.5*PI-THETA-ALFA)
      IF(NP5.EQ.0)GO TO 209
  207 PRINT 208,WN,DTH,DPH,THR,ALF
  208 FORMAT(1H0,*   WIND SPEED = *F7.2*KNOTS   THETA=*F7.2*DEG   PHI=*
     *     F7.2*DEG*/32X,*GRID =*F7.2*DEG   ALF=*F7.2*DEG*)
```

```
      GO TO 84
  209 CONTINUE
      PRINT 210, WN,DTH,DPH
  210 FORMAT(1H1,*     WIND SPEED = *F7.2*KNOTS    THETA=*F7.2*DEG    PHI=*
     *      F7.2*DEG*//*       DRIFT CURRENT U AND V IN FT/SEC/100*//)
      DO 202 M=1,MMAX2
      DO 202 N=1,NMAX2
  202 KONVERT(N,M)=UW(N,M)*100.
      PRINT 9,((KONVERT(N,M),N=1,NMAX2),M=1,MMAX2)
      PRINT 10
      DO 203 M=1,MMAX2
      DO 203 N=1,NMAX2
  203 KONVERT(N,M)=VW(N,M)*100.
      PRINT 9,((KONVERT(N,M),N=1,NMAX2),M=1,MMAX2)
      PRINT 201
  201 FORMAT(1H1,*      HARBOR DEPTH IN FT AND DRIFT ANGLE IN DEGREES*//)
      DO 204 M=1,MMAX2
      DO 204 N=1,NMAX2
  204 KONVERT(N,M)=DEP(N,M)
      PRINT 9,((KONVERT(N,M),N=1,NMAX2),M=1,MMAX2)
      PRINT 10
      DO 205 M=1,MMAX2
      DO 205 N=1,NMAX2
  205 KONVERT(N,M)=ALPHA(N,M)
      PRINT 9,((KONVERT(N,M),N=1,NMAX2),M=1,MMAX2)
    9 FORMAT(1H 32I4)
   10 FORMAT(1H0)
   84 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CONC     (C,Y,X,KONVERT,U,V,NMAX2,MMAX2,
     1 IREGION,NR1,MR1,DEP,UW,VW,ALPHA,CPO,UU,VV,NBMX,MBMX)
      DIMENSION DEP(NMAX2,MMAX2),UW(NMAX2,MMAX2),VW(NMAX2,MMAX2),
     *              ALPHA(NMAX2,MMAX2)
      DIMENSION  C(NMAX2,MMAX2),X(NMAX2,MMAX2),Y(NMAX2,MMAX2)
      DIMENSION U(NMAX2,MMAX2),V(NMAX2,MMAX2)
      DIMENSION UU(NBMX,MBMX),VV(NBMX,MBMY)
      DIMENSION KONVERT(NMAX2,MMAX2),IREGION(NR1,MR1)
      DIMENSION CS(36,30),CR(36,30),CO(36,30)
      COMMON /ALL/ IK,II,IP,MAJOR,ICYCLE,MCYCLE,IMAJ,ITIME,
     *                IDIV,IN,IM
      COMMON /BAY/ NIND,NST,MST,DX,DXH,DXR,NLINE(150),MF(150),ML(150)
      COMMON /OLD/ MP1,MP2,MP3,MP4,MP5
      COMMON /ABC/    NOY,MOX,DRO,SIG,VCM
      COMMON /DEF/ UC(32,26),VC(32,26)
      COMMON /EGH/ CON ,MO,MINI,IOP
      DATA PI,G,RO,ANU/3.14159,981.0,1.0,0.012/
      JHOUR=ITIME
      TEIV =(1.45/1.14)**4*(1.0/(ANU*DRO*G))**(1./3.)/3600.
      TEVS =(1.45/2.3)**2*(DRO*G*         ANU)**(1./3.)*RO/SIG/3600.
      TEM=(( 1.0 /2.3)**4*(RO**2*ANU)/SIG**2)**(1./3.)/3600.
      COEI=1.14*(G*DRO)**0.25/(2.54*12.)
      COEV=1.45*(DRO*G                 /ANU**0.5)**(1./6.)/(2.54*12.)
      COES=2.30*(SIG**2          /(RO**2*ANU))**0.25/(2.54*12.)
      TM=100.**(4./3.)*SQRT(VCM)*TEM
      ARM=100.*VCM**(3./8.)
      SS=VCM/(PI*ARM**2)*1000.
      ICO=0
      IR=2*MINI
      IF(IK.LE.5)  GO TO 90
      IP=1
   90 CPSUM=0.
      CPO1=0.
      DO 100 N=1,NMAX2
      DO 100 M=1,MMAX2
      Y(N,M)=N*DX
      X(N,M)=M*DX
      CR(N,M)=0.
      CS(N,M)=0.
  100 CONTINUE
      IF(IK.GT.5) GO TO 350

      DO 300 IA=1,IR
      IF(IK.GT.0) GO TO 25
      IMAJ=IMAJ+1
      READ(7)((UC(N,M),N=1,NMAX2),M=1,MMAX2)
     1        ,((VC(N,M),N=1,NMAX2),M=1,MMAX2)
      IF(IMAJ-50) 20,21,20
   21 REWIND 7
      READ(7)
      IMAJ=0
      MAJOR=MAJOR+1
   20 CONTINUE
```

```
      IF(IK.LT.0)
     *CALL WINDS(KONVERT,NMAX2,MMAX2,IREGION,NR1,MR1,DEP,UW,VW,ALPHA)
   25 CONTINUE
      DO 110 N=1,NMAX2
      DO 110 M=1,MMAX2
      U(N,M)=600.*(UC(N,M)+UW(N,M))
  110 V(N,M)=600.*(VC(N,M)+VW(N,M))
      IF(IDIV.EQ.1) GO TO 150
      DO 120 N=1,NBMX
      DO 120 M=1,MBMX
      NN=IN+(N-1)/IDIV
      MM=IM+(M-1)/IDIV
      UU(N,M)=U(NN,MM)
      VV(N,M)=V(NN,MM)
  120 CONTINUE
      DO 140 NUM=1,NIND
      NST=NLINE(NUM)
      MFST=MF(NUM)
      MLST=ML(NUM)
      DO 140 MST=MFST,MLST
      IF(C(NST,MST).EQ.0.) GO TO 140
      CALL TRNSPRT (Y(NST,MST),X(NST,MST),UU,VV,DXR,NBMX,MBMX,
     1  IREGION,NR1,MR1)
  140 CONTINUE
      GO TO 300
  150 CONTINUE
      DO 200 NUM=1,NIND
      NST=NLINE(NUM)
      MFST=MF(NUM)
      MLST=ML(NUM)
      DO 200 MST=MFST,MLST
      IF(C(NST,MST)   .EQ.0.) GO TO 200
      CALL TRNSPRT (Y(NST,MST),X(NST,MST),U,V,    DXR, NMAX2,MMAX2,
     1  IREGION,NR1,MR1)
  200 CONTINUE
  300 CONTINUE

  350 CONTINUE
      JHOUR=JHOUR+NINT
      THOUR=JHOUR
      IF(IOP) 940,950,900
  940 ICO=1
      GO TO 400
  950 IF(THOUR.GT.TM) ICO=1
      GO TO 400
  900 IF(IOP-2) 1000,2000,2000
 2000 CONTINUE
      YN=Y(NOY,MOX)*DXR
      XM=X(NOY,MOX)*DXR
      NOY=YN+0.5
      MOX=XM+0.5
      IF(THOUR.LE.TM) GO TO 2100
      JC=THOUR-TM
      IF(JC.LT.NINT) GO TO 2100
      ICO=1
```

```
      GO TO 400
 2100 CONTINUE
      IF((MOY.LT.1) .OR. (MOX.LT.1)) GO TO 560
      ROND=0.586
      CALL OILELM(VCM,THOUR,RET,S,TEIV,TEVS,TEM,COEI,COEV,COES)
      CALL SPREAD(RET,S,MOY ,MOX ,DX,IREGION,NR1,MR1,CQ,ROND)
      DO 33 NUT=1,NIND
      L=NLINE(NUT)
      MES =MF(NUT)
      MLS =ML(NUT)
      DO 33 K=MES ,MLS
      CPNM=CQ(L,K)
      CR(L,K)=CR(L,K)+CPNM
      CPSUM=CPSUM+CPNM
   33 CONTINUE
      GO TO 560

 1000 CONTINUE
  400 TINT=NINT
      ROND=0.586
      DO 560 NUM=1,NIND
      NST=NLINE(NUM)
      MFST=MF(NUM)
      MLST=ML(NUM)
      DO 500 MST=MFST,MLST
      YN=Y(NST,MST)*DXR
      XM=Y(NST,MST)*DXR
      N=YN+0.5
      M=XM+0.5
      S=C(NST,MST)
      IF(S.EQ.0.) GO TO 500
      IF(ICQ.NE.0) GO TO 490
      GCM=S*DX*DX*(12.*2.54)**3
      CALL     OILELM(GCM,TINT,RET,S,TEIV,TEVS,TEM,COEI,COEV,COES)
      CALL SPREAD(RET,S,N,M,DX,IREGION,NR1,MR1,CQ,ROND)
      DO 66 NUT=1,NIND
      L=NLINE(NUT)
      MES =MF(NUT)
      MLS =ML(NUT)
      DO 66 K=MES ,MLS
      CPNM=CQ(L,K)
      CR(L,K)=CR(L,K)+CPNM
      CPSUM=CPSUM+CPNM
   66 CONTINUE
      GO TO 500
  490 CONTINUE
      IF((N.LT.1) .OR. (M.LT.1)) GO TO 500
      IF((N.GT.NMAX2) .OR. (M.GT.MMAX2)) GO TO 500
      CR(N,M)=CR(N,M)+S
      CPSUM=CPSUM+S
  500 CONTINUE

  560 CP01=CPSUM*DX*DX
      DO 570 NUM=1,NIND
      N=NLINE(NUM)
```

```
      MFST=MF(JHR)
      MLST=ML(JHR)
      DO 570 M=MFST,MLST
      C(M,1)     =CR(N,M) +CS(N,M)
  570 CONTINUE
      DO 620 N=1,NMAX2
      DO 620 M=1,MMAX2
      CNO=C(N,M)
      OTC         =    1000.*CNO*12. *2.54
      KONVERT(N,M)=OTC+0.5
      IF(OTC.GT.9999.) GO TO 620
      ICOR=10 *KONVERT(N,M)
      IF(ICOR.NE.0) KONVERT(N,M)=-99
  620 CONTINUE
      IF(ICP.GT.2) KONVERT(NOY,MOX)=-99

      CPA=CP01
      MOLFT=CPA*(12.*2.54)**3/3790.+0.5
      CALL  PRINTC (KONVERT,NMAX2,MMAX2,NP1,NP2,NP3,JHOUR,MOLFT,IDIV,
     *          IN,IM,NRPX,MRPX)
      IF((NOY.LT.1) .OR. (MOX.LT.1)) RETURN
      IF((NOY.GT.NMAX2) .OR. (MOX.GT.MMAX2)) RETURN
      CP0=CPA
      IF(ICYCLE.EQ.NCYCLE)  RETURN
      ICYCLE=ICYCLE+1
      GO TO 90
      END
```

```
      SUBROUTINE PRINTC (NAR,MMAX2,NMAX2,NP1,NP2,NP3,JHOUR,NO,IDIV,
     *            IN,IM,MNMX,MRMX)
      INTEGER ASTK
      DIMENSION IPR(128),MO(32)
      DIMENSION NAR(NMAX2,MMAX2)
      DIMENSION NUM(10)
      DATA IB/1H /
      DATA ASTK/1H*/
      DATA IO/1H0/
      DATA (NUM(I),I=1,10)/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
      MMX=MMAX2
      IF(IDIV.GT.1) MMX=MRMX
      NP=NP2-NP1+1
      IF(NP-NP3) 20,20,21
   20 NPP1=NP1
      NPP2=NP2
      IFLG=0
      GO TO 22
   21 NPP1=NP1
      NPP2=NP3+NP1-1
      IFLG=1
   22 CONTINUE
      NPIN=(NPP1-1)*4+1
      NP34=NPP2*4
      DO 25 I=NPP1,NPP2
   25 NO(I)=IN+(I-1)/IDIV
      PRINT 600,        JHOUR,         (NO(I),I=NPP1,NPP2)
  600 FORMAT(*1      THICKNESS OF OILFILM IN CM/1000, AT END OF HOUR *,
     1I4/                                        //* M N =*,I2,31I4)
      DO 100 M=1,MMX
      MO1=IM+(M-1)/IDIV
      DO 10 I=1,NP34
   10 IPR(I)=IB
      DO 1 N=NPP1,NPP2
      J=4*N
      L=NAR(N,M)
      IF(L.LT.0) GO TO 7
      IF (L .GT. 9999) GO TO 2
      IF (L.GE. 1000) GO TO 6
      IF (L .GE. 100) GO TO 3
      IF (L .GE. 10) GO TO 4
      IPR(J)=NUM(L+1)
      GO TO 1
    2 IPR(J)=ASTK
      IPR(J-1)=ASTK
      IPR(J-2)=ASTK
      IPR(J-3)=ASTK
      GO TO 1
    7 IPR(J)=IO
      IPR(J-1)=IO
      IPR(J-2)=IO
      IPR(J-3)=IO
      GO TO 1
    6 N1=L/1000
```

```
      IPR(J-3)=NUM(N1+1)
      N1=I-1000*N1
      N2=N1/100
      IPR(J-2)=NUM(N2+1)
      N2=N1-100*N2
      N3=N2/10
      IPR(J-1)=NUM(N3+1)
      N1=N2-10*N3
      IPR(J)=NUM(N1+1)
      GO TO 1
    3 N1=I/100
      IPR(J-2)=NUM(N1+1)
      N1=I-100*N1
      N2=N1/10
      IPR(J-1)=NUM(N2+1)
      N1=N1-10*N2
      IPR(J)=NUM(N1+1)
      GO TO 1
    4 N1=I/10
      IPR(J-1)=NUM(N1+1)
      N1=I-10*N1
      IPR(J)=NUM(N1+1)
    1 CONTINUE
      PRINT 5, NQ1,(IPR(I),I=1,NP34)
    5 FORMAT (/*  *,I2,1X,128A1)
  100 CONTINUE
      IF (IFLG .EQ. 0) RETURN
      NPP1=NPP2+1
      NPP2=NP2
      IFLG=0
      GO TO 22
      END
```

```
      SUBROUTINE SPREAD(RET,S,NOY,MOX,DX,IREGION,NR1,MR1,CO,ROND)
      DIMENSION IREGION(NR1,MR1),CO(36,30),CT(36,30)
      DO 5 I=1,36
      DO 5 J=1,30
    5 CO(I,J)=CT(I,J)=0.
      NR=RET/DX
      CPO=3.14159*RET**2*S
      IF(NR.LT.1) GO TO 30
      N1=NOY-NR
      N2=NOY+NR
      M1=MOX-NR
      M2=MOX+NR
      NC=0
      MC=0
      IF(N1.LT.1) NC=-N1+1
      IF(M1.LT.1) MC=-M1+1
      NA=N1+NC
      NB=N2+NC
      MA=M1+MC
      MB=M2+MC
      CPSUM=0.
      DO 10 N=NA,NB
      DO 10 M=MA,MB
      ND=N-NC
      MD=M-MC
      NN=ND+2
      MM=MD+2
      CALL CHECK(NN,MM,NR1,MR1)
      CC=S
      IF(IREGION(NN,MM).EQ.2) GO TO 8
      ZA=ND-NOY
      ZB=MD-MOX
      NS=SQRT(ZA*ZA+ZB*ZB) + ROND
      IF(NS.GT.NR) GO TO 8
      IF((ND.LT.1).OR.(MD.LT.1)) GO TO 10
      IF((ND.GT.NR1).OR.(MD.GT.MR1)) GO TO 10
      CALL SCAN(ND,MD,NOY,MOX,IREGION,NR1,MR1,IL)
      IF(IL.EQ.0) GO TO 9
    8 CC=0.
    9 CT(N,M)=CC
   10 CPSUM=CPSUM+CC
      FAC=CPSUM*DX*DX/CPO
      DO 20 N=NA,NB
      DO 20 M=MA,MB
      ND=N-NC
      MD=M-MC
      IF((ND.LT.1).OR.(MD.LT.1)) GO TO 20
      IF((ND.GT.NR1).OR.(MD.GT.MR1)) GO TO 20
      CO(ND,MD)=CT(N,M)/FAC
   20 CONTINUE
      RETURN
   30 CO(NOY,MOX)=CPO/(DX*DX)
      RETURN
      END
```

```
      SUBROUTINE OILFLM(VCM,T,RET,S,TEIV,TEVS,TEM,COEI,COEV,COES)
      TS=T*3600.
      VCM3=VCM**(1./3.)
      TIMEI=VCM3*TEIV
      TIMEV=VCM3**2*TEVS
      RMAXCM=100.*VCM**(3./8.)
      TM=RMAXCM**(4./3.)*TEM
      RET=S=0.
      IF(T.EQ.0.) GO TO 6
      IF(TIMEI.GE.TIMEV) GO TO 10
      IF(T.LE.TIMEI) GO TO 1
   10 IF(T.LE.TIMEV) GO TO 2
      GO TO 3
    1 RET=COEI*SQRT(TS)*VCM**0.25
      GO TO 5
    2 RET=COEV*TS**0.25*VCM**(1./3.)
      GO TO 5
    3 RET=COES*TS**0.75
    5 S=VCM/(3.14159*RET**2)/(12.*2.54)**3
    6 RETURN
      END
```

```
      SUBROUTINE TRNSPRT (Y,X,U,V,    DXR,    NMX,MMX,IREGION,NR1,MR1)
      DIMENSION U(NMX,MMX),V(NMX,MMX)
      DIMENSION IREGION (NR1,MR1)
      YSAV=Y
      XSAV=X
      YTEMP=Y*DXR
      NTEMP=YTEMP
      N=YTEMP+.5
      XTEMP=X*DXR
      MTEMP=XTEMP
      M=XTEMP+.5
      NM1=N-1
      MM1=M-1
      TEMPN=NTEMP
      TEMPM=MTEMP
      NV=NM1
      MV=MM1
      NU=NM1
      MU=MM1
      IF(MTEMP.EQ.M) GO TO 100
      IF(MTEMP.LT.M) GO TO 200
      MV=M+1
      MU=M
      GO TO 200
  100 NV=N
      NU=N+1
      IF(MTEMP.LT.M) GO TO 200
      MV=M+1
      MU=M
  200 CALL CHECK(N  ,M  ,NMX,MMX)
      CALL CHECK(NM1,MM1,NMX,MMX)
      CALL CHECK(NV ,MV ,NMX,MMX)
      CALL CHECK(NU ,MU ,NMX,MMX)
      IF((TEMPN.EQ.YTEMP).AND.(TEMPM.EQ.XTEMP)) GO TO 201
      VM=V(NV,MV)+V(NM1,M)+V(N,M)
      UM=U(NU,MU)+U(N,MM1)+U(N,M)
      GO TO 202
  201 VM=  1.5 * (V(NM1,M)+V(N,M))
      UM=  1.5 * (U(N,MM1)+U(N,M))
  202 X=X+UM
      Y=Y+VM
      NO=Y*DXR+0.5
      MO=X*DXR+0.5
      NF=Y*DXR+2.5
      MF=X*DXR+2.5
      CALL CHECK(NF,MF,NR1,MR1)
      ITMP=IREGION(NF,MF)
      IF(ITMP -2) 400,401,400
  400 IF((NO.LT.1).OR.(MO.LT.1)) GO TO 50
      IF((NO.GT.NR1).OR.(MO.GT.MR1)) GO TO 50
      CALL SCAN(NO,MO,N,M,IREGION,NR1,MR1,IL)
      IF(IL.EQ.0) GO TO 50
  401 Y=YSAV
      X=XSAV
   50 RETURN
      END
```

```
      SUBROUTINE SCAN(N,M,NO,MO,IREGION,NR1,MR1,IL)
      DIMENSION IREGION(NR1,MR1)
      IF((N.EQ.NO).AND.(M.EQ.MO)) GO TO 5
      IF(N-NO) 1,1,3
    1 IA=N
      IB=NO
      NSGN=-1
      GO TO 2
    3 IA=NO
      IB=N
      NSGN= 1
    2 IF(M-MO) 4,4,6
    4 JA=M
      JB=MO
      MSGN=-1
      GO TO 7
    6 JA=MO
      JB=M
      MSGN= 1
    7 IL=0
      CM=JB-JA
      CN=IB-IA
      IF(CN.EQ.0.) GO TO 11
      AFA=CM/CN
      NGN=NSGN*MSGN
      KI=IA
      KJ=JA
      IF(NGN) 15,16,16
   15 KI=IB
      KJ=JB
   16 IF(CM.GT.CN) GO TO 12
      DO 10 I=IA,IB
      AI=I-IA
      BJ=AI*AFA
      LJ=BJ+0.5
      J=KJ+NGN*LJ
      II=I+2
      JJ=J+2
   10 IF(IREGION(II,JJ).EQ.2)IL=1
      GO TO 8
   11 DO 20 J=JA,JB
      II=N+2
      JJ=J+2
   20 IF(IREGION(II,JJ).EQ.2) IL=1
      GO TO 8
   12 DO 30 J=JA,JB
      AJ=J-JA
      BI=AJ/AFA
      LI=BI+0.5
      I=KI+NGN*LI
      II=I+2
      JJ=J+2
   30 IF(IREGION(II,JJ).EQ.2)IL=1
      GO TO 8
```

```
5    II=0
8    RETURN
     END




     SUBROUTINE UPDAT(C,NMX,MMX,CPO,DX,S)
     DIMENSION C(NMX,MMX)
     DIMENSION NN(40),MM(40)
     READ 1, NDXY,(NN(I),MM(I),I=1,NDXY)
1    FORMAT(20I4)
     AN=NDXY
     S=CPO/(AN*DX*DX)
     DO 10 I=1,NDXY
     N=NN(I)
     M=MM(I)
10   C(N,M)=S
     RETURN
     END




     SUBROUTINE CHECK(N,M,NN,MM)
     N=MAX0(1,MIN0(NN,N))
     M=MAX0(1,MIN0(MM,M))
     RETURN
     END
```

TABLES

I - VI

TABLE I

RANGE OF MARKER FROM RESPONDERS RECORDED AS A FUNCTION OF TIME

Date: October 5, 1973

Marker No. 1			Marker No. 2			Marker No. 3		
Time	Range A (meters)	Range B (meters)	Time	Range A (meters)	Range B (meters)	Time	Range A (meters)	Range B (meters)
12:28	2990	4310	12:17	3234	4137	12:21	2948	4011
12:48	2765	4293	12:45	3006	4068	12:40	2762	3975
13:01	2665	4255	12:56	2920	4015	12:58	2600	3880
13:17	2560	4240	13:09	2780	3975	13:14	2435	3820
13:33	2450	4196	13:28	2636	3881	13:37	2227	3709
13:49	2364	4162	13:44	2515	3800	13:54	2093	3600
14:07	2260	4125	14:03	2360	3705	14:47	1660	3398
14:55	1930	4023	14:12	2290	3660	15:12	1535	3292
15:20	1821	3996	*14:15	2475	3390	15:31	1400	3213
15:40	1715	3935	14:43	2270	3215	15:53	1320	3110
15:59	1590	3860	15:06	2120	3100			
			15:28	2030	2978			
			15:46	1930	2907			
			16:03	1880	2801			

*Relocation of marker

TABLE II

TIDE TABLE
TIME AND HEIGHT OF HIGH AND LOW WATERS
IN SAN PEDRO BAY

Date	Time	Height, ft
October 5, 1973	0609	3.9
	1045	3.1
	1614	4.5
	2331	0.8
October 10, 1973	0126	0.8
	0737	5.6
	1356	0.4
	2003	5.0
February 6, 1974	0205	1.1
	0814	6.8
	1506	-1.5
	2124	4.9
February 11, 1974	0632	0.9
	1221	3.7
	1803	1.2
February 12, 1974	0047	5.0
	0748	1.0
	1343	3.0
	1845	1.8

TABLE III

RANGE OF MARKER FROM RESPONDERS RECORDED AS A FUNCTION OF TIME

Date: October 10, 1973

Marker No. 1			Marker No. 2		
Time	Range A (meters)	Range B (meters)	Time	Range A (meters)	Range B (meters)
11:40	3494	3305	11:43	3373	3487
12:11	3605	2840	12:20	3263	3245
12:37	3618	2565	13:27	3316	2580
13:48	4227	2002	14:20	3690	2108
14:30	4748	1927	14:40	3906	1945
15:25	5398	2040	15:15	4315	1828
			15:30	4438	1812

Marker No. 3			Marker No. 4		
Time	Range A (meters)	Range B (meters)	Time	Range A (meters)	Range B (meters)
11:48	3265	3709	12:00	3087	3915
12:24	3234	3450	12:30	3015	3798
13:35	3405	2630	13:41	2960	3260
14:22	3760	2080	14:15	3085	2885
14:36	3930	1923	14:53	3400	2380
			15:10	3550	2180
			15:37	3852	1946

TABLE IV

WIND SPEED AND DIRECTION AND RANGE OF SLICK CENTROID FROM RESPONDERS RECORDED AS A FUNCTION OF TIME

Date: February 6, 1974

Time	Range A (meters)	Range B (meters)	Range C (meters)	Range D (meters)	Wind Speed (kts)	Wind Direction (deg)*
13:33		2035		3770	10	60
13:58		2240		3510	10	60
14:29		2369	3041	3380	0	-

* magnetic

TABLE V

WIND SPEED AND DIRECTION AND RANGE OF SLICK CENTROID FROM RESPONDERS RECORDED AS A FUNCTION OF TIME

Date: February 11, 1974

Time	Range A (meters)	Range B (meters)	Range C (meters)	Range D (meters)	Wind Speed (knots)	Wind Direction (deg)*
12:56	3135	4541	871	2215	9.0	215
13:33	3030	4650	770	-	6.0	207
14:13	2450	3940	1475	1920	9.0	215
14:28	2370	-	1640	2050	11.0	212
14:42	2420	-	1771	2190	11.0	210
14:57	2530	3490	1880	2380	11.0	210
15:13	2675	3392	1984	2560	11.0	210
15:26	-	3256	2130	2710	12.0	220
15:43	2760	3120	2290	2840	12.0	208
15:58	2873	2984	2450	3010	12.0	220

* magnetic

TABLE VI

WIND SPEED AND DIRECTION AND RANGE OF SLICK CENTROID FROM RESPONDERS RECORDED AS A FUNCTION OF TIME

Date: February 12, 1974

Time	Range A (meters)	Range B (meters)	Range C (meters)	Range D (meters)	Wind Speed (knot)	Wind Direction		
						Reading From Compass (deg)*	Angle Relative to Bearing Line of Lighthouse From Boat (deg) (positive clockwise)	Resolved Direction (deg)*
15:27	2349	2945	2450	-	9.5	211	21	220
15:58	2575	2654	2724	-	7.5	218	15	220
16:16	2737	2410	-	-	8.5	218	16	224
16:30	2845	2350	-	-	7.6	216	10	218
16:44	2950	2129	3249	-	8.5	216	18	226
16:59	3058	1990	3396	-	8.4	209	0	209
17:28	3208	1742	3660	3961	7.5	170	-14	194
17:59	3586	1395	4100	4415	8.0	230	26	239
18:26	3932	1170	4475	4821	8.1	240	32	247

* magnetic

FIGURES

1 - 30

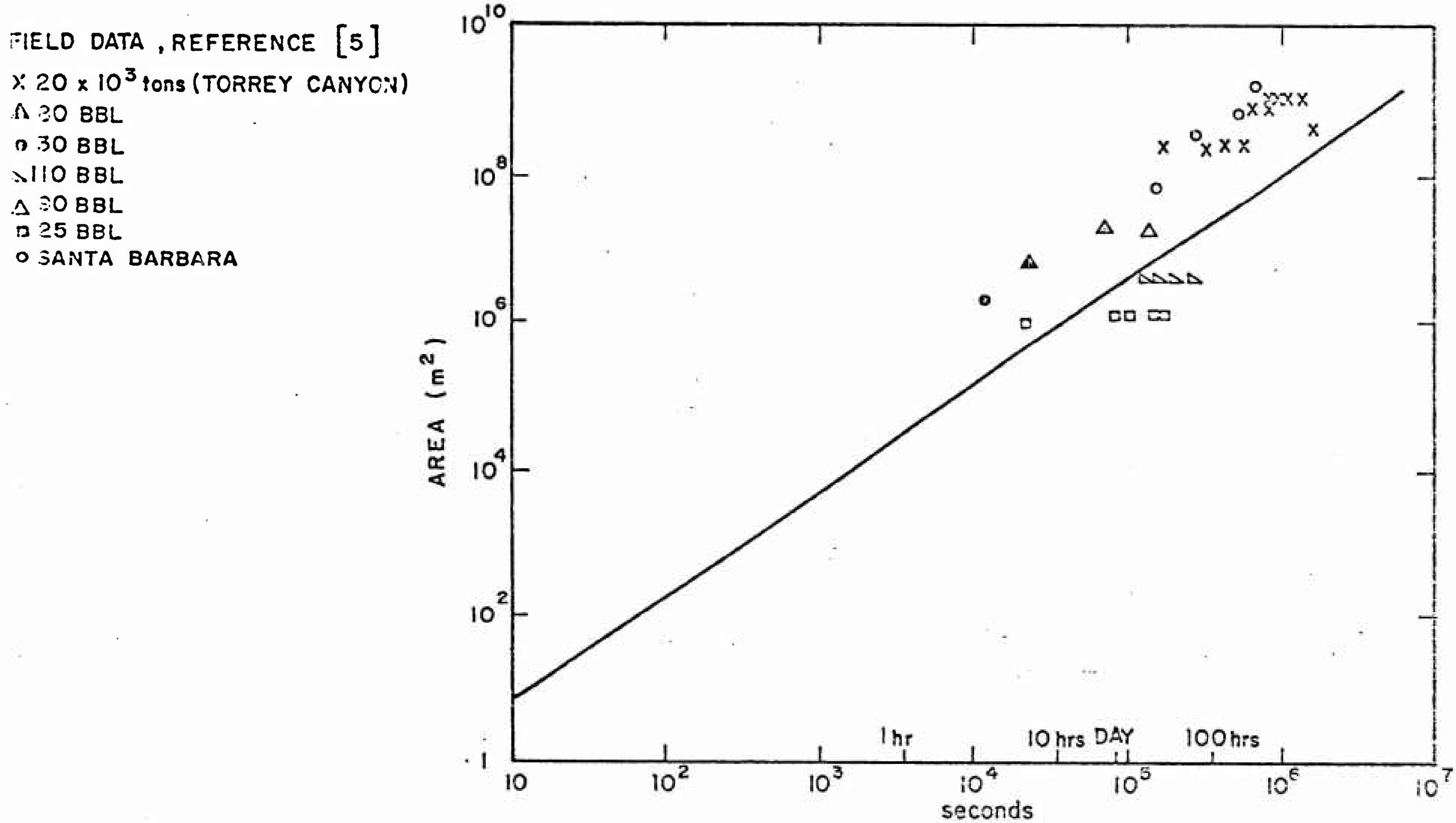

Figure 1 - Slick Area Increased Due to Surface Tension Spread

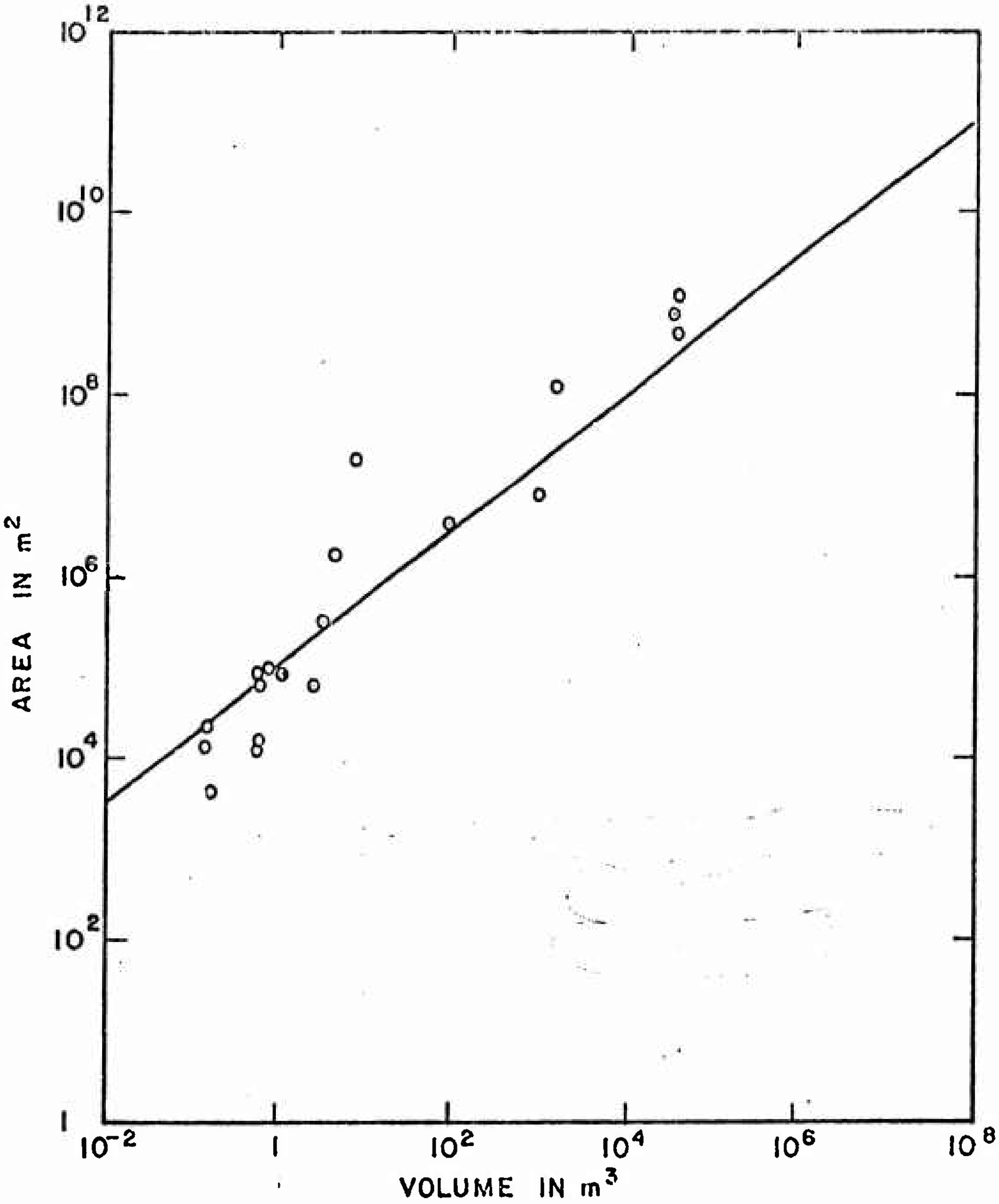

Figure 2 - Maximum Slick Area as a Function of Volume, Reference [5]

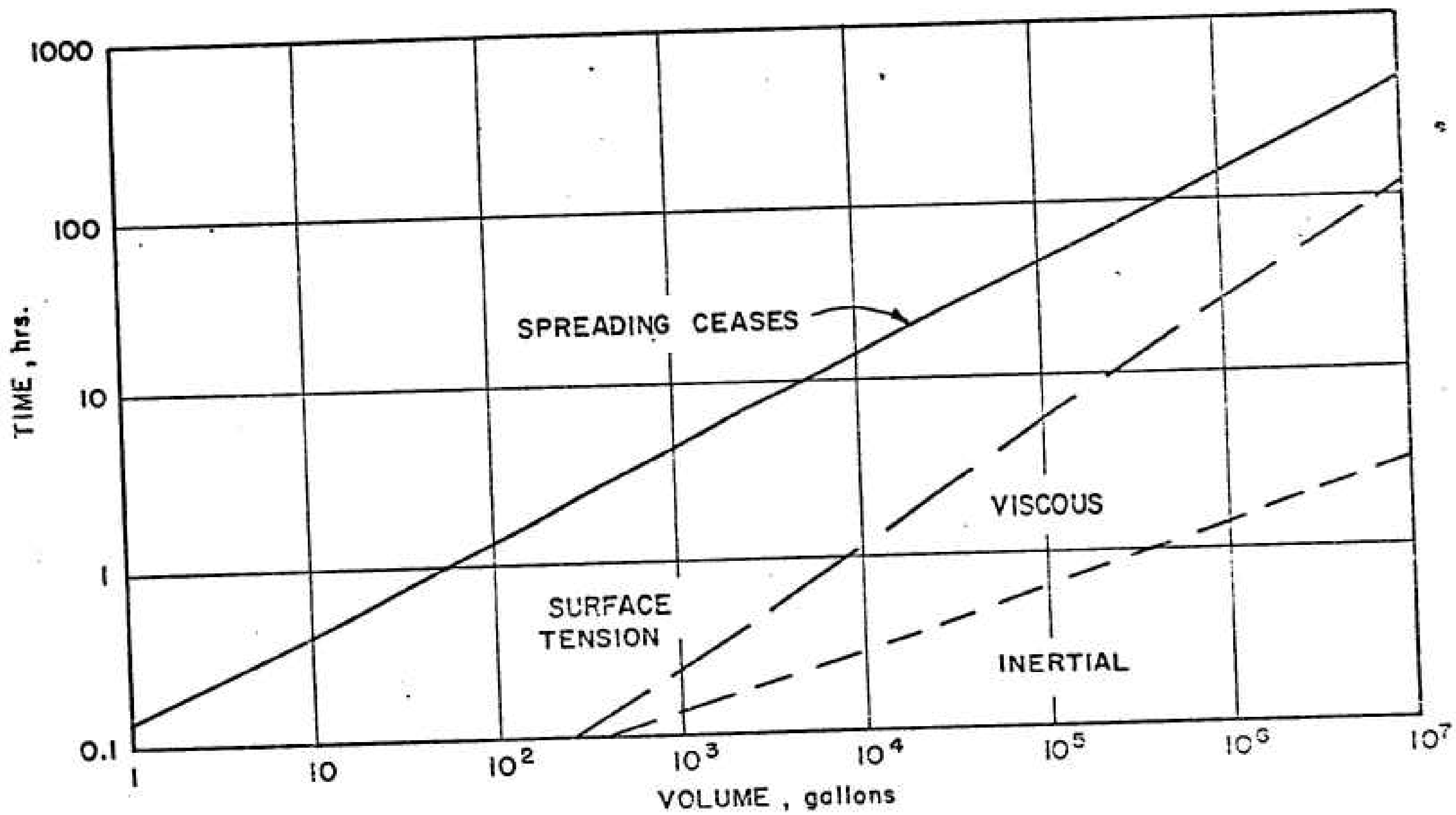

Figure 3 - Duration of Spreading Regimes

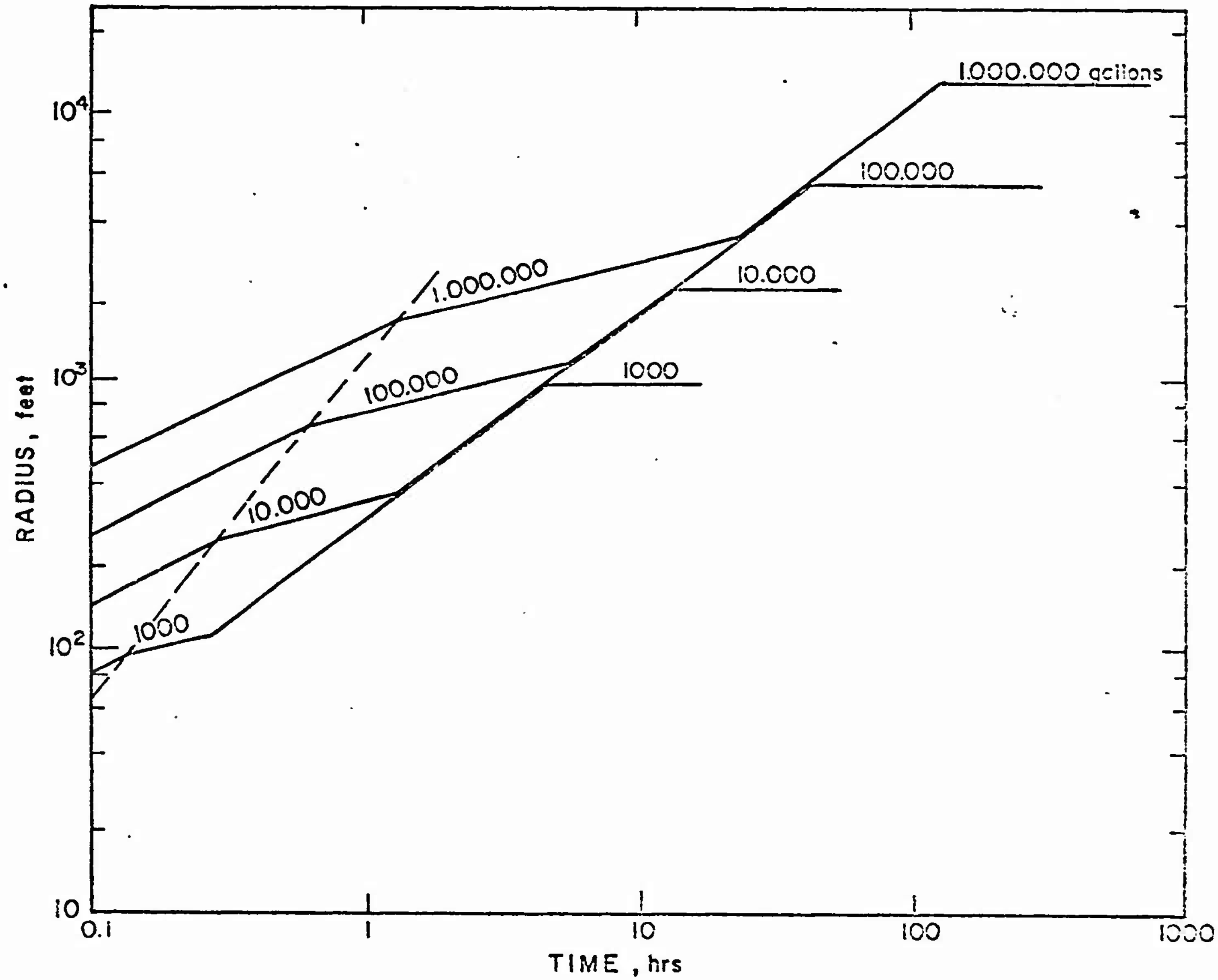

Figure 4 - Slick Radius Increase as a Function of Time for Various Size Spills

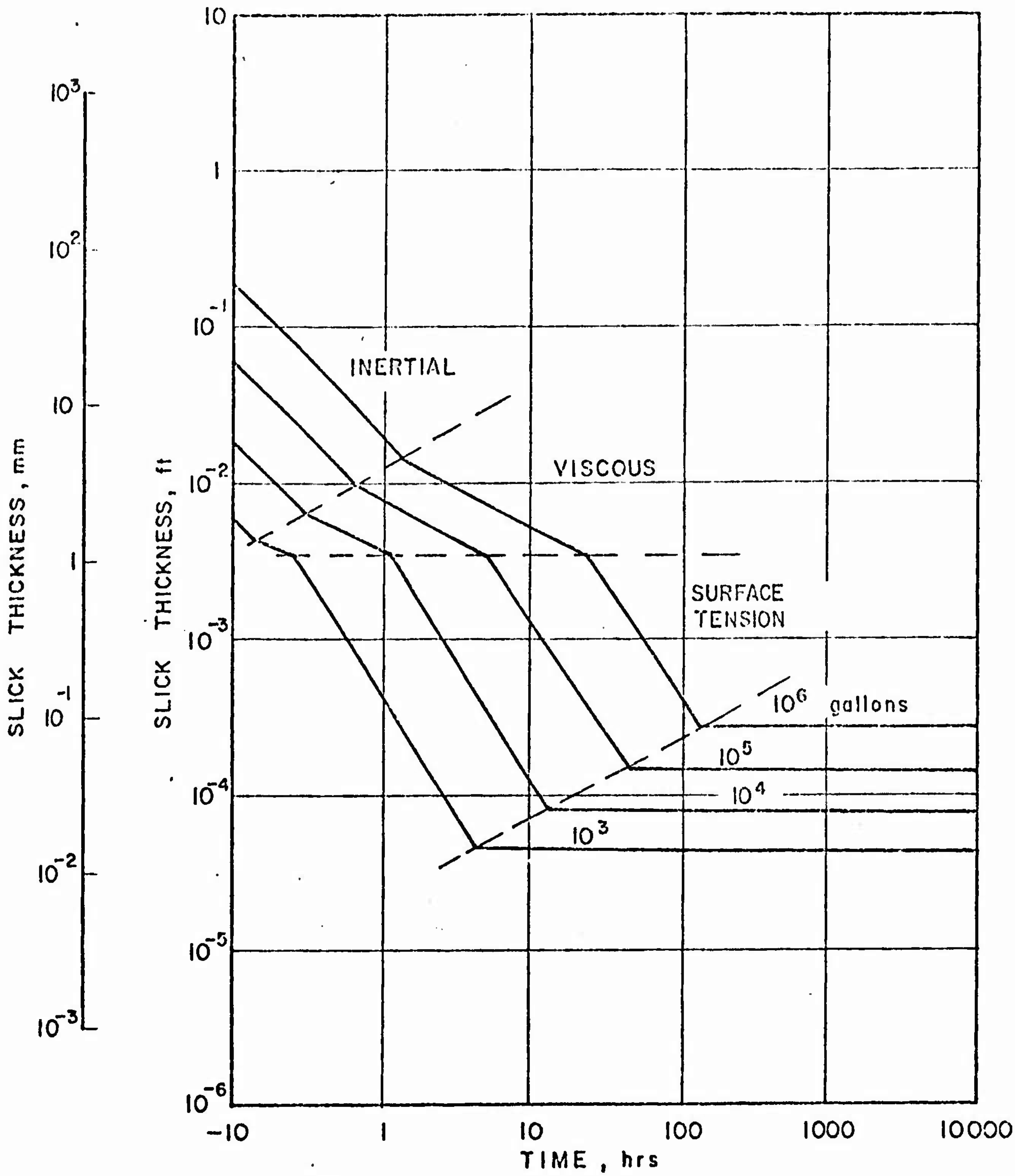

Figure 5 - Nominal Thickness Decrease as a Function of Time

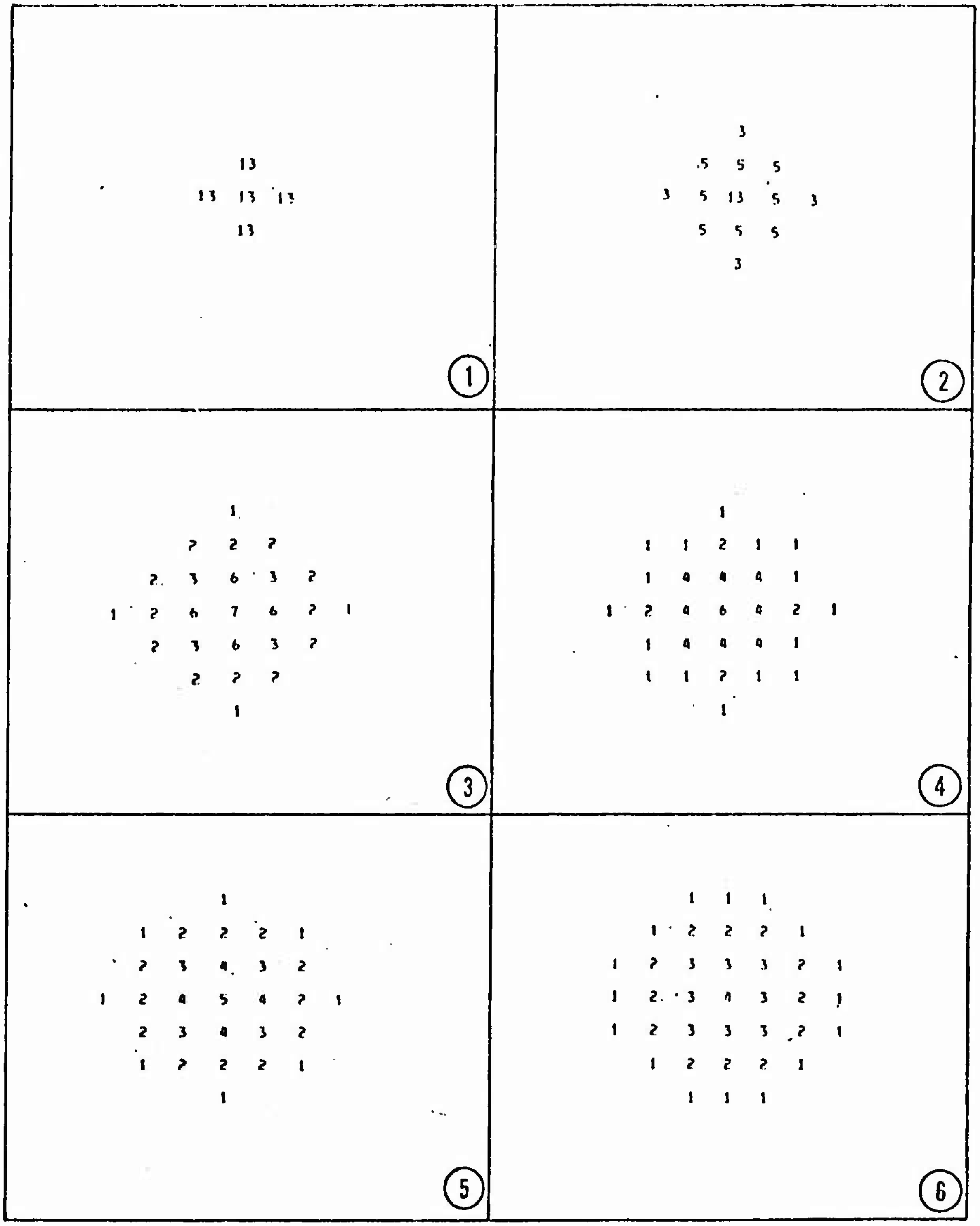

Figure 6 - Sample Results of Simulation for Circular Spreading of Oil on Water

Volume = 1000 gallons
Δs = 250 ft
Δt = 1 hour

(Numbers indicate film thickness in 10^{-3}cm and numerals at the lower right corner of each frame indicate time in hours after spill occurs.)

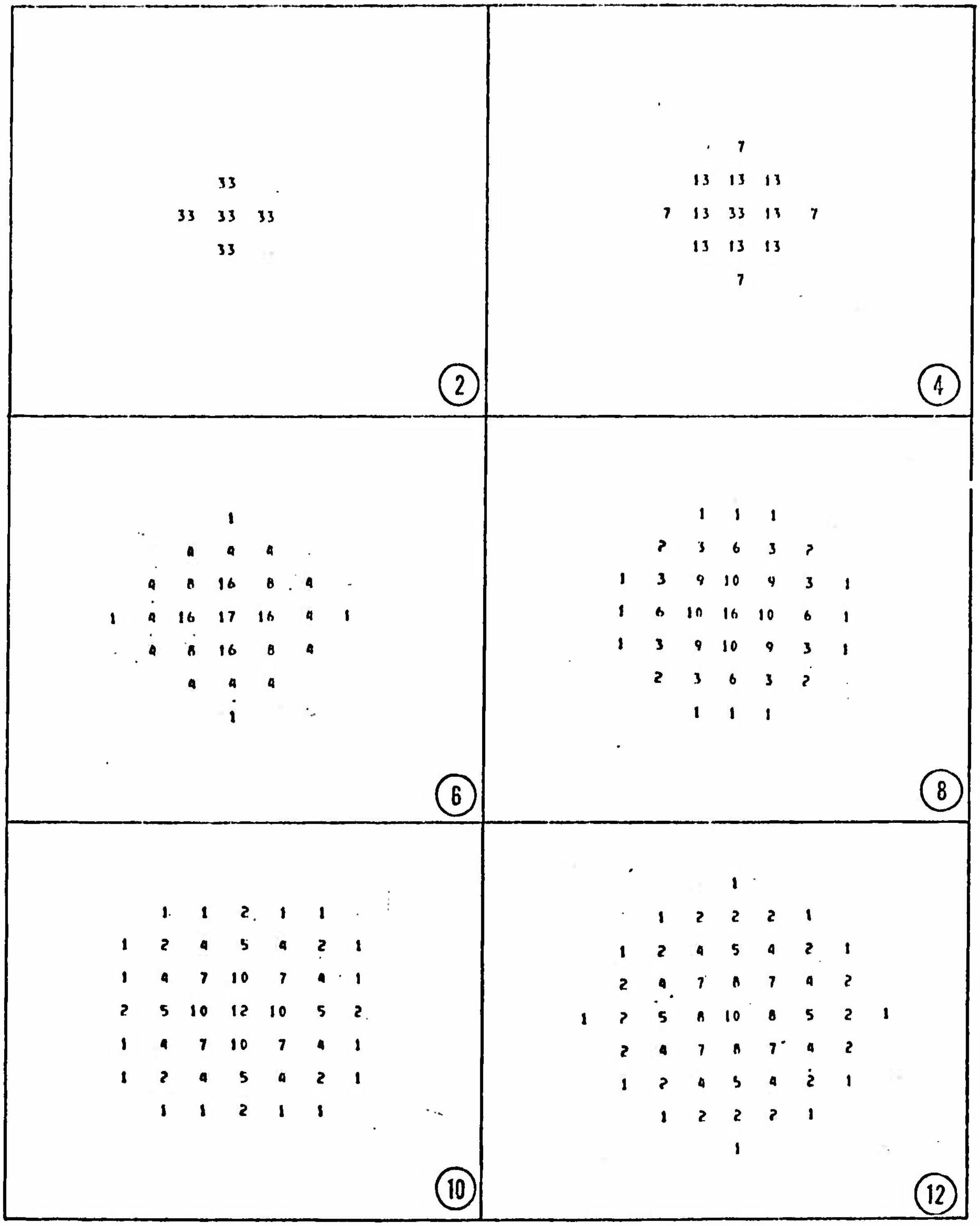

Figure 7 - Sample Results of Simulation for Circular Spreading of Oil on Water

Volume = 10,000 gallons
Δs = 500 ft
Δt = 2 hours

(Numbers indicate film thickness in 10^{-3}cm and numerals at the lower right corner of each frame indicate time in hours after spill occurs.)

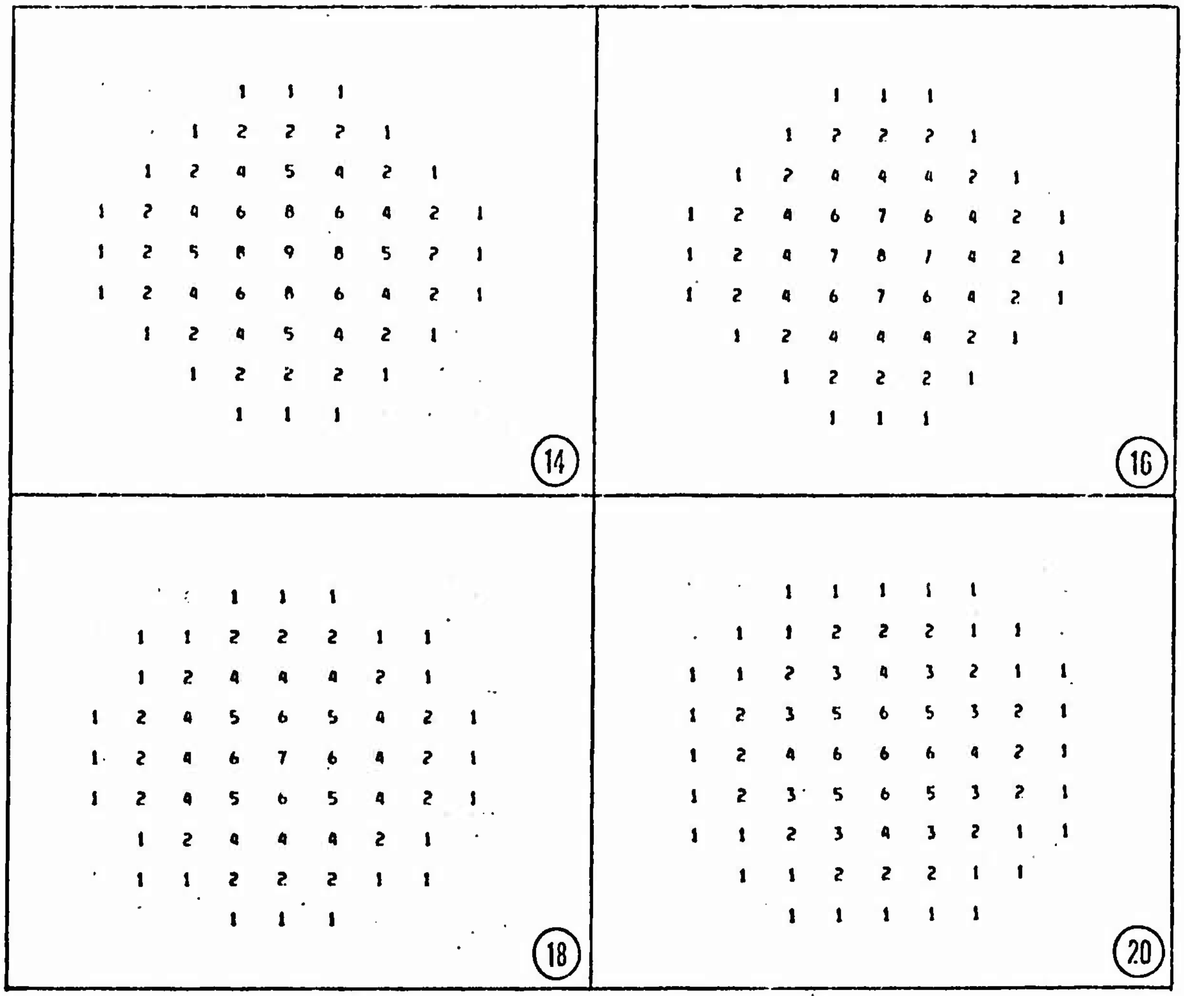

Figure 7 - (continued)

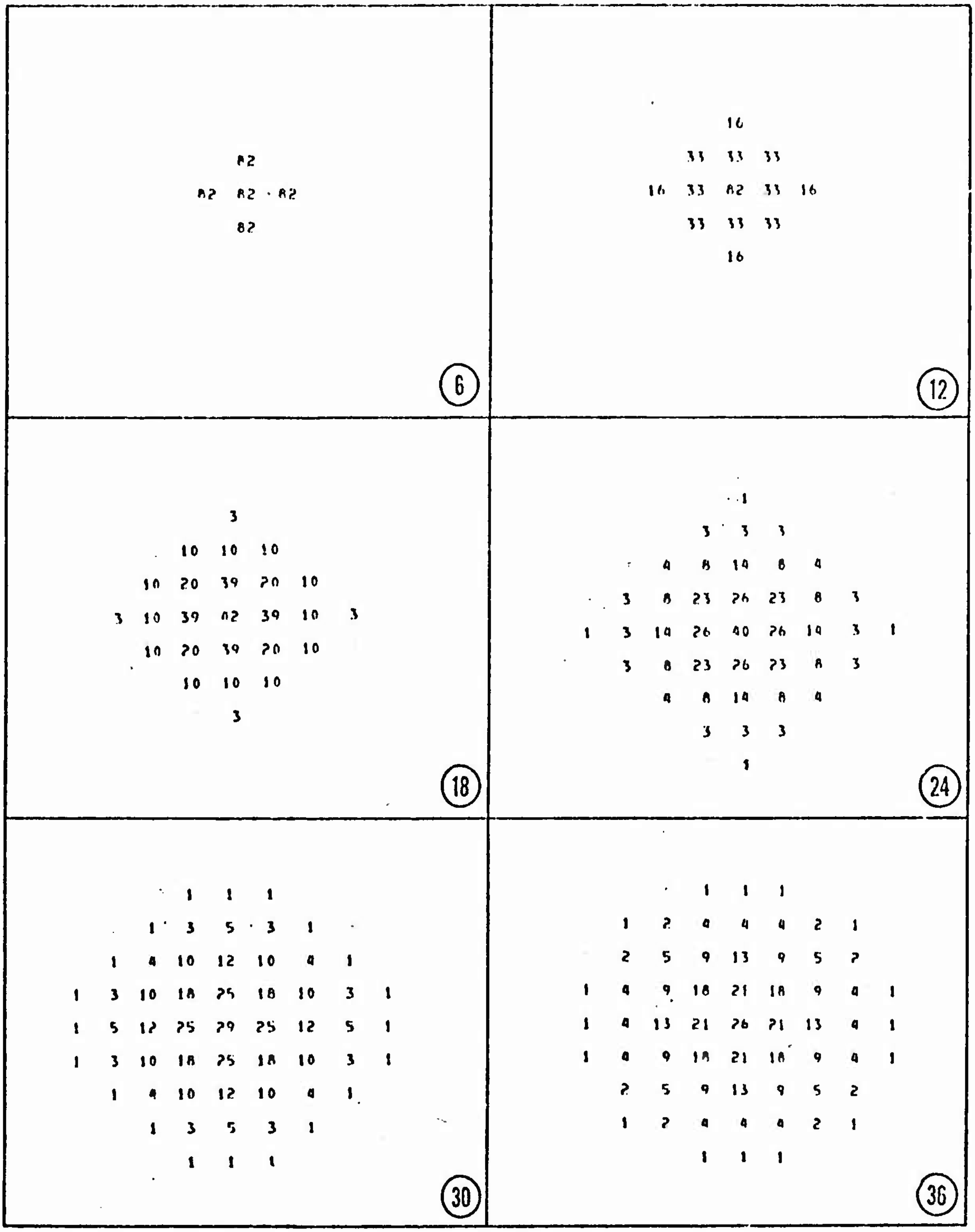

Figure 8 - Sample Results of Simulation for Circular Spreading of Oil on Water

Volume = 100,000 gallons
Δs = 1000 ft
Δt = 6 hours

(Numbers indicate film thickness in 10^{-3}cm and numerals at the lower right corner of each frame indicate time in hours after spill occurs.)

		1	1	1	1	1		
	1	2	4	5	4	2	1	
1	2	5	10	11	10	5	2	1
1	4	10	16	19	16	10	4	1
1	5	11	19	22	19	11	5	1
1	4	10	16	19	16	10	4	1
1	2	5	10	11	10	5	2	1
	1	2	4	5	4	2	1	
		1	1	1	1	1		

42

		1	2	2	2	1		
	1	3	5	5	5	3	1	
1	3	6	9	11	9	6	3	1
2	5	9	15	17	15	9	5	2
2	5	11	17	20	17	11	5	2
2	5	9	15	17	15	9	5	2
1	3	6	9	11	9	6	3	1
	1	3	5	5	5	3	1	
		1	2	2	2	1		

48

				1	1	1				
		1	1	2	2	2	1	1		
	1	1	3	5	5	5	3	1	1	
	1	3	6	9	10	9	6	3	1	
1	2	5	9	13	15	13	9	5	2	1
1	2	5	10	15	17	15	10	5	2	1
1	2	5	9	13	15	13	9	5	2	1
	1	3	6	9	10	9	6	3	1	
	1	1	3	5	5	5	3	1	1	
		1	1	2	2	2	1	1		
				1	1	1				

54

				1	1	1				
		1	1	2	2	2	1	1		
	1	2	3	5	5	5	3	2	1	
	1	3	6	9	10	9	6	3	1	
1	2	5	9	12	14	12	9	5	2	1
1	2	5	10	14	16	14	10	5	2	1
1	2	5	9	12	14	12	9	5	2	1
	1	3	6	9	10	9	6	3	1	
	1	2	3	5	5	5	3	2	1	
		1	1	2	2	2	1	1		
				1	1	1				

60

Figure 8 - (continued)

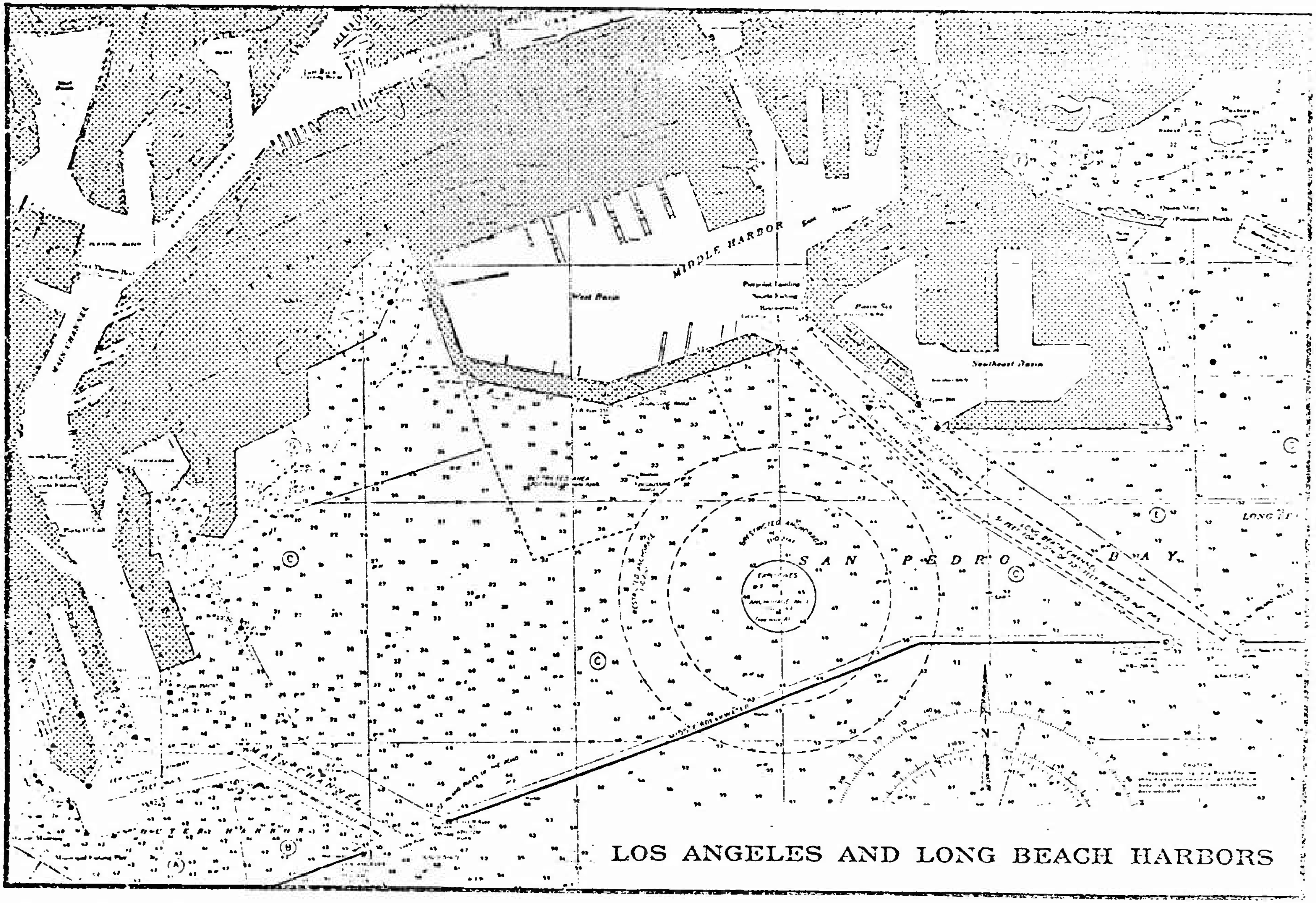

Figure 9 - Map of San Pedro Bay

M \ N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	*	*	*	*	35	35	35	35	*	*	35	35	35	35	35	35	35	35	35	55	55	55	55	55	45	45	45	45	*	*	*
3	*	*	*	*	*	*	35	35	35	35	35	35	35	*	*	*	*	*	*	*	*	*	*	55	55	55	*	*	*	*	*	*
4	*	*	*	*	*	*	35	35	35	35	35	*	*	*	*	*	*	*	*	*	*	*	*	*	47	*	*	*	*	*	*	*
5	*	*	*	*	*	35	35	35	35	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	47	*	*	*	*	*	*	*
6	*	*	*	*	*	35	35	35	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	60	*	*	*	*	*	*	*
7	*	*	*	*	*	35	35	*	*	*	*	*	*	13	14	*	35	40	45	50	50	50	60	*	60	*	50	50	*	*	*	*
8	*	*	*	*	*	35	*	*	*	*	*	*	*	18	19	*	35	40	45	50	50	50	60	*	60	50	50	50	*	*	*	*
9	*	*	*	*	*	35	*	18	18	*	*	*	18	19	20	*	*	40	45	50	50	50	60	60	60	50	50	50	*	*	*	*
10	*	*	*	*	*	35	*	22	20	*	17	19	21	23	23	21	*	*	45	50	50	50	60	60	60	*	*	*	*	*	*	*
11	*	*	*	*	*	35	*	14	*	*	19	21	22	25	25	26	35	*	*	*	25	25	60	60	60	*	*	*	*	*	*	*
12	*	*	31	*	*	35	*	17	18	20	22	24	27	26	27	28	29	46	50	*	*	*	*	45	*	62	62	*	*	55	*	*
13	*	31	31	*	*	35	*	20	21	22	25	27	28	29	29	31	31	35	35	35	39	48	48	57	*	*	62	*	*	55	*	*
14	*	33	35	*	35	25	20	23	23	26	26	30	33	32	33	31	33	36	36	36	38	39	38	58	51	*	62	62	55	55	55	*
15	*	13	33	*	35	35	33	25	26	29	31	32	33	34	34	35	37	37	50	66	66	69	67	67	51	51	42	*	55	55	*	*
16	*	24	47	47	47	47	40	32	32	35	41	37	35	38	38	41	39	39	50	55	66	67	70	71	72	51	46	*	*	*	*	*
17	*	40	42	42	40	41	47	47	41	42	42	42	40	40	40	39	41	43	61	69	65	70	72	71	73	70	47	46	48	48	*	*
18	*	25	*	42	42	42	42	45	47	41	40	41	41	43	43	44	45	44	45	46	69	70	71	70	68	66	60	49	49	49	49	*
19	*	45	25	*	43	43	43	42	47	43	43	46	46	46	49	49	48	48	48	49	48	48	49	48	66	68	71	50	51	51	51	*
20	*	55	52	25	*	*	*	*	*	48	40	*	*	*	*	*	*	*	*	*	*	*	*	*	*	52	60	60	54	54	52	*
21	*	65	62	60	60	60	60	55	52	50	50	52	53	58	55	55	55	55	55	54	53	53	53	53	52	*	*	25	54	55	55	*
22	*	73	69	70	70	70	63	60	55	55	55	58	59	62	63	61	59	59	57	55	55	55	55	55	55	55	53	*	*	55	55	*
23	*	80	80	80	77	72	65	60	58	58	60	60	61	63	64	64	63	60	60	60	58	57	57	57	57	55	55	55	55	56	25	*
24	*	86	82	83	80	76	73	69	65	65	65	64	63	66	68	68	66	65	64	62	63	62	60	60	58	58	58	59	58	58	57	*
25	*	88	87	89	87	84	80	78	78	73	73	70	61	65	67	73	73	73	70	70	68	66	64	61	61	62	61	61	61	60	58	*
26	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Figure 10 - Grid Mesh Used in the Example Problem - Grid Spacing Δs = 1000 ft
(Numbers indicate water depth in feet)

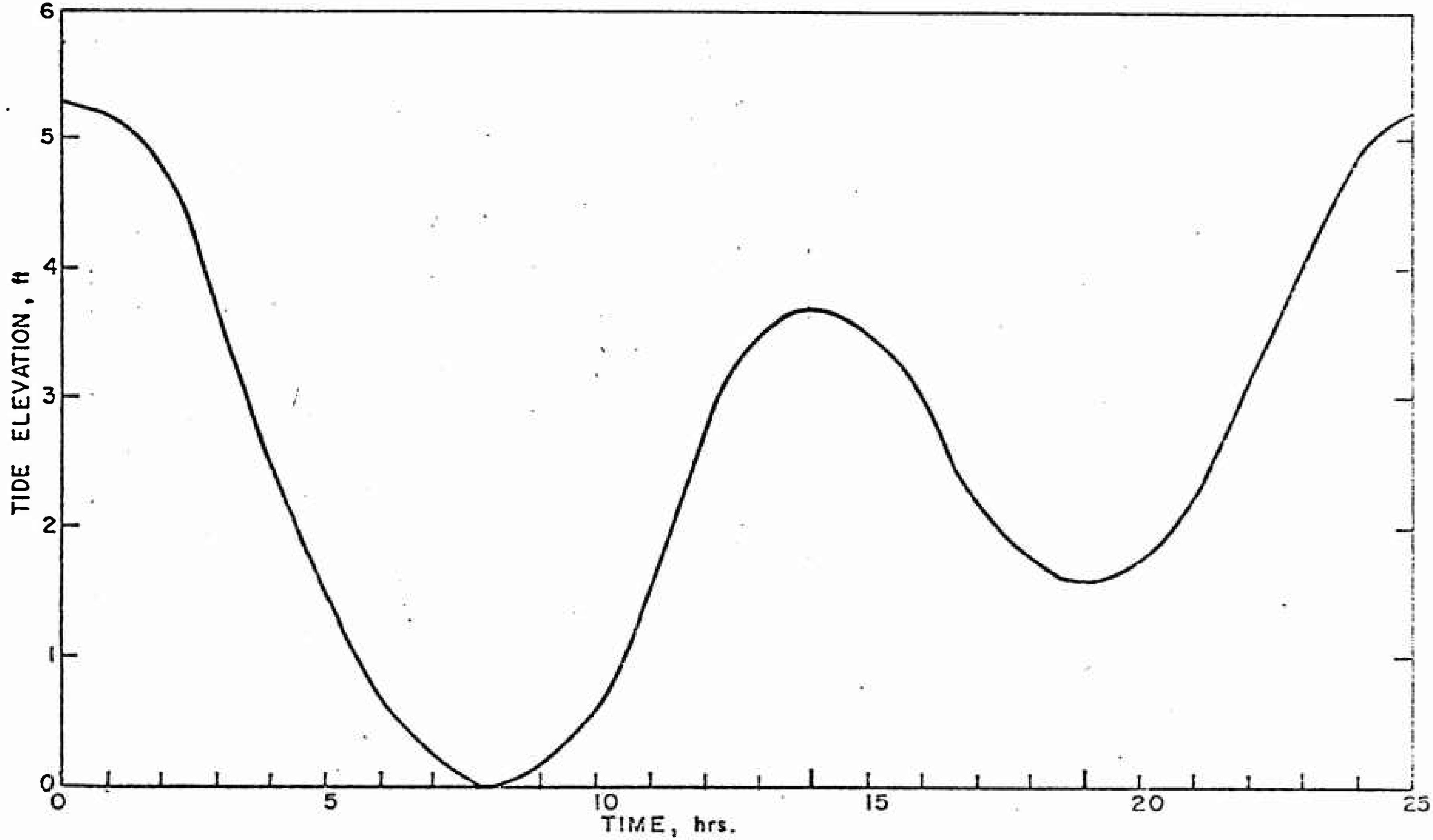

Figure 11 - Typical Tidal Fluctuation in San Pedro Bay

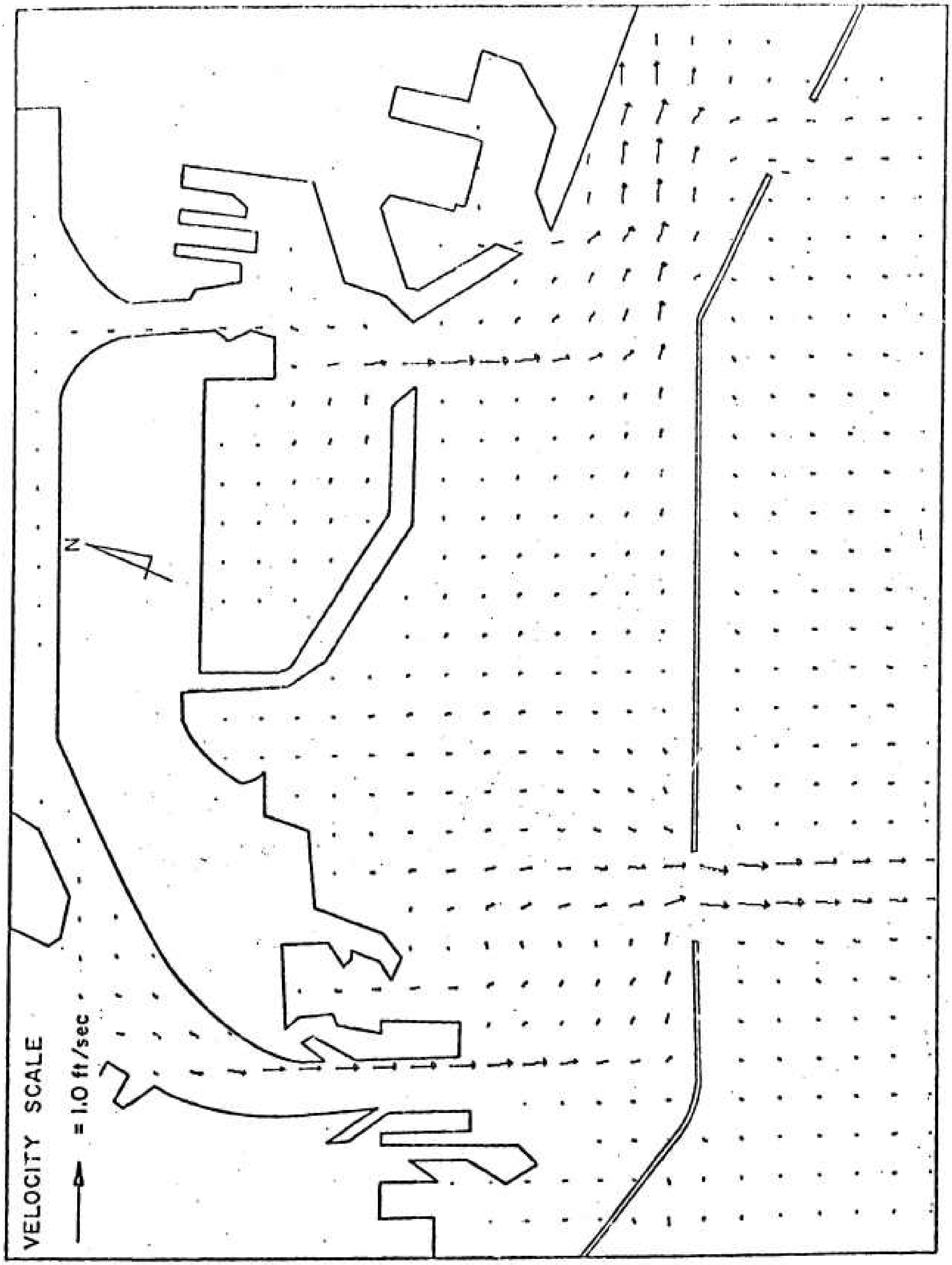

Figure 12a - Current Field at Hour 3.5, No Wind

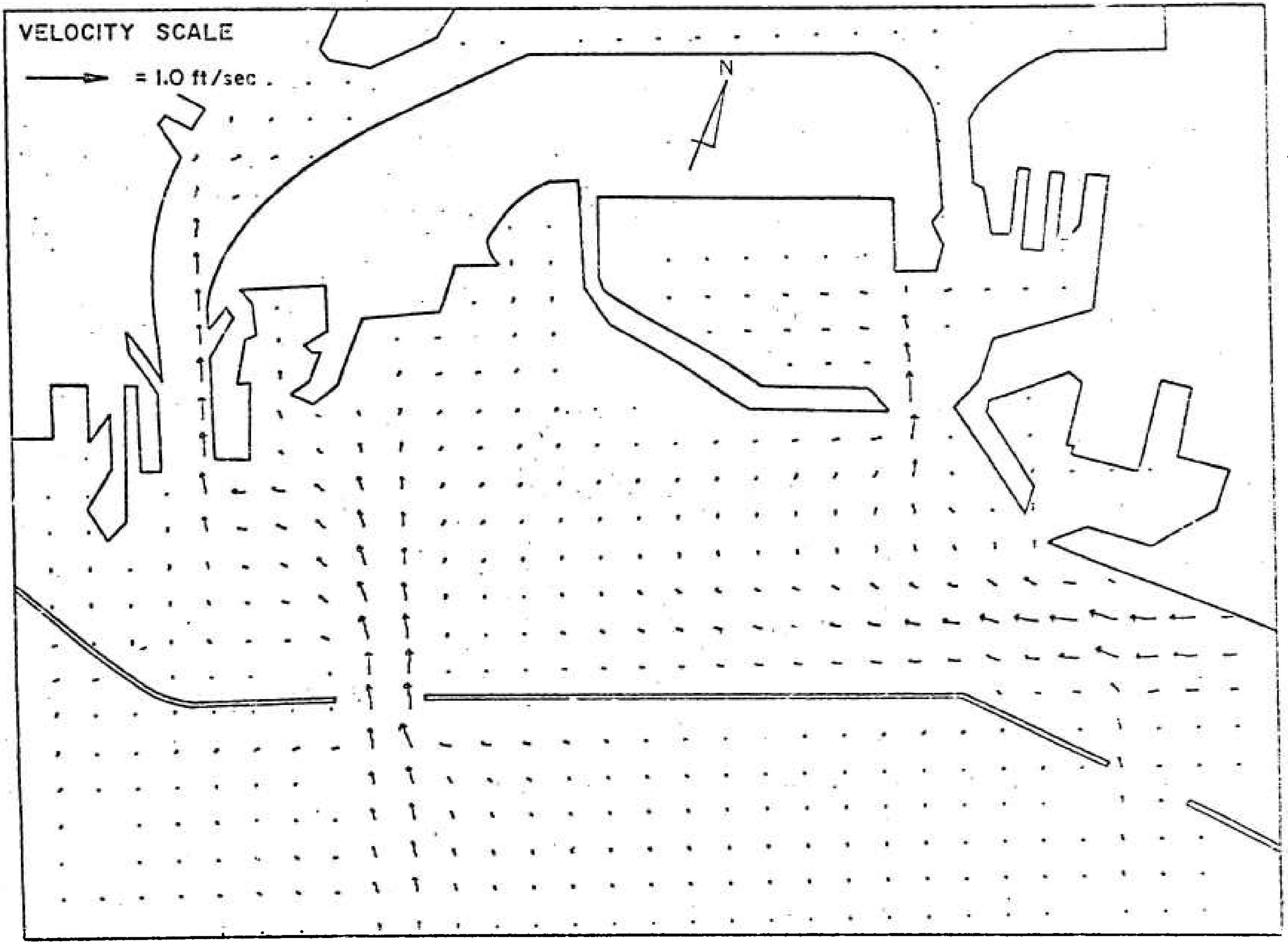

Figure 12b - Current Field at Hour 10.5, No Wind

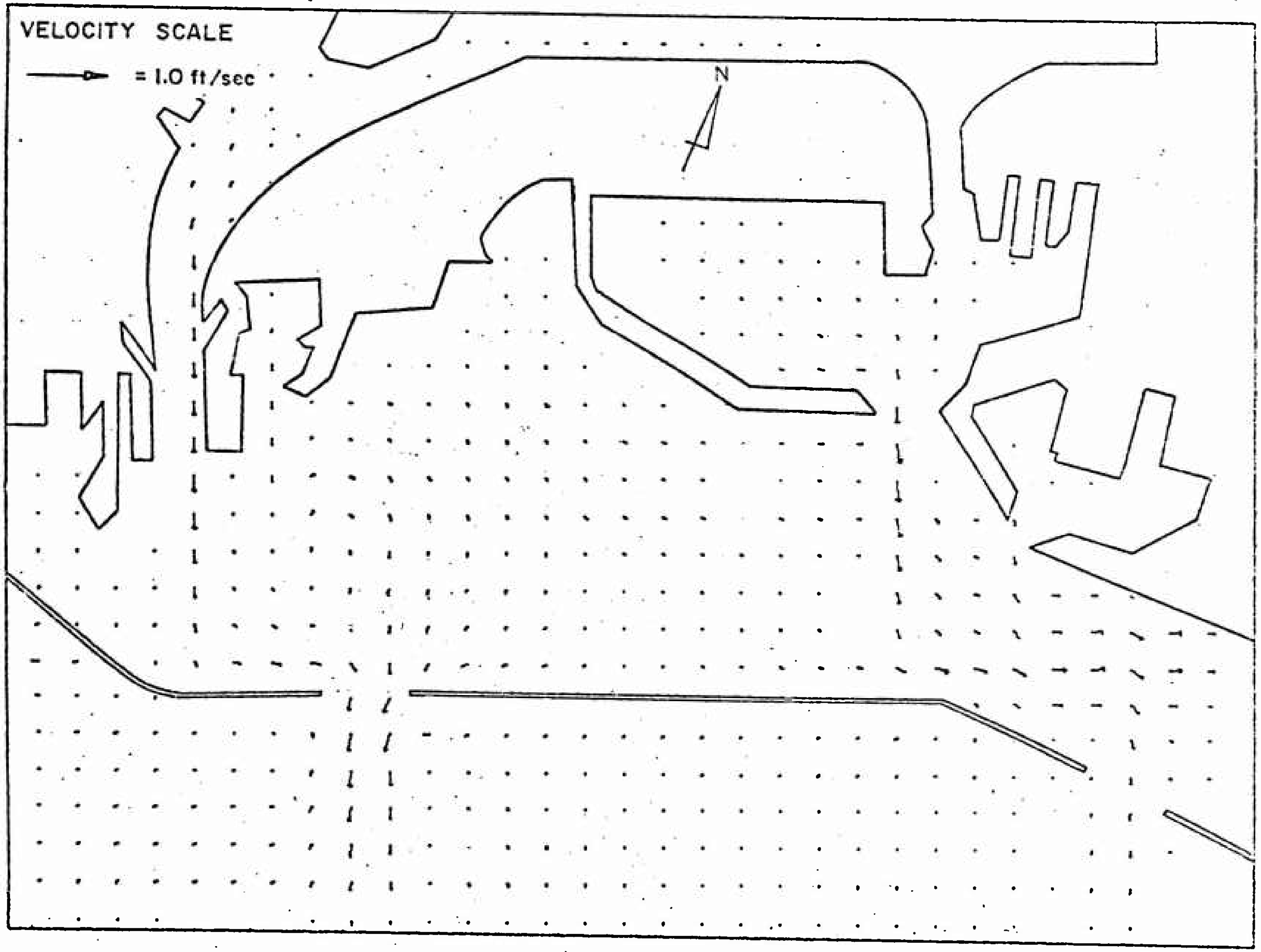

Figure 12c - Current Field at Hour 16, No Wind

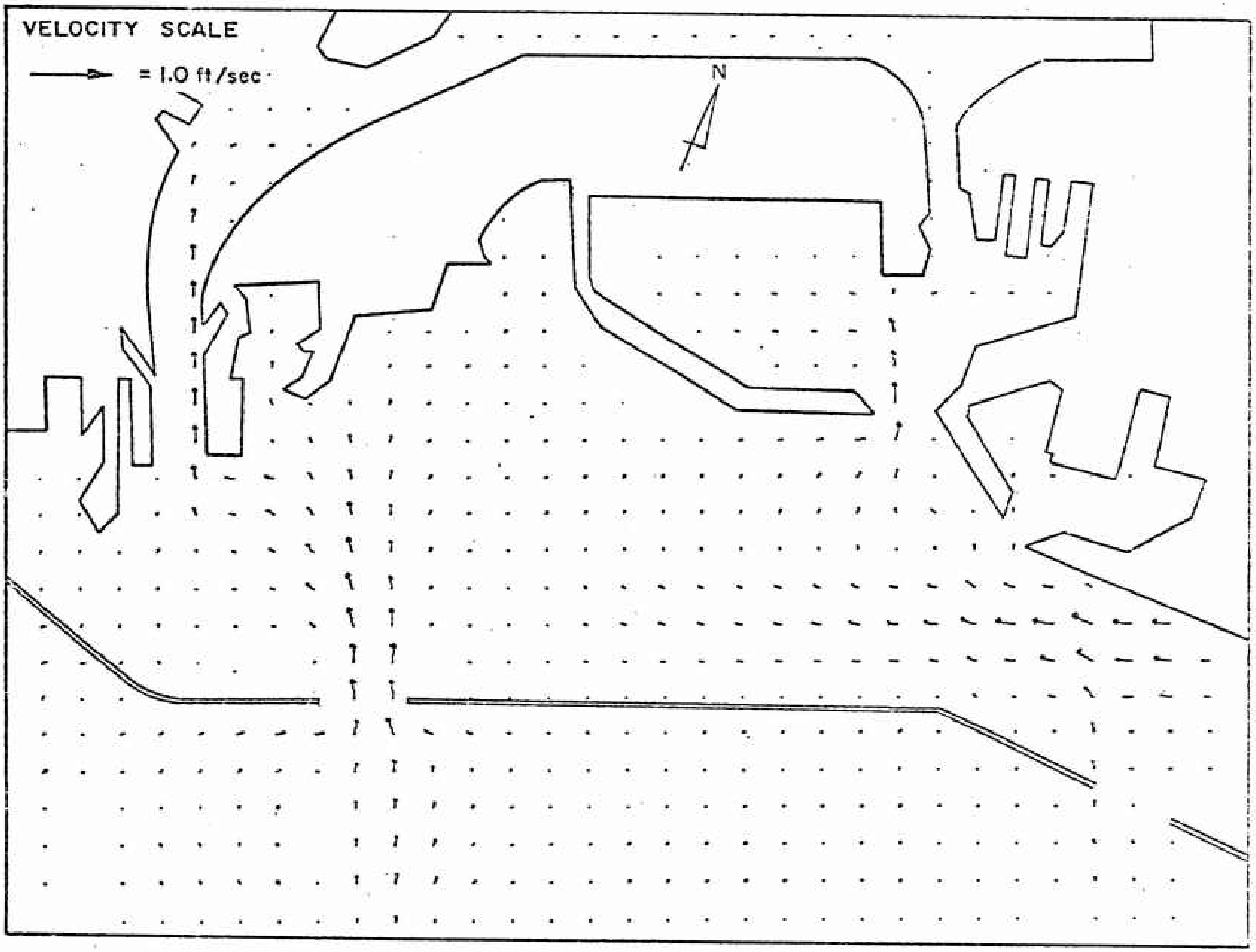

Figure 12d - Current Field at Hour 21.5, No Wind

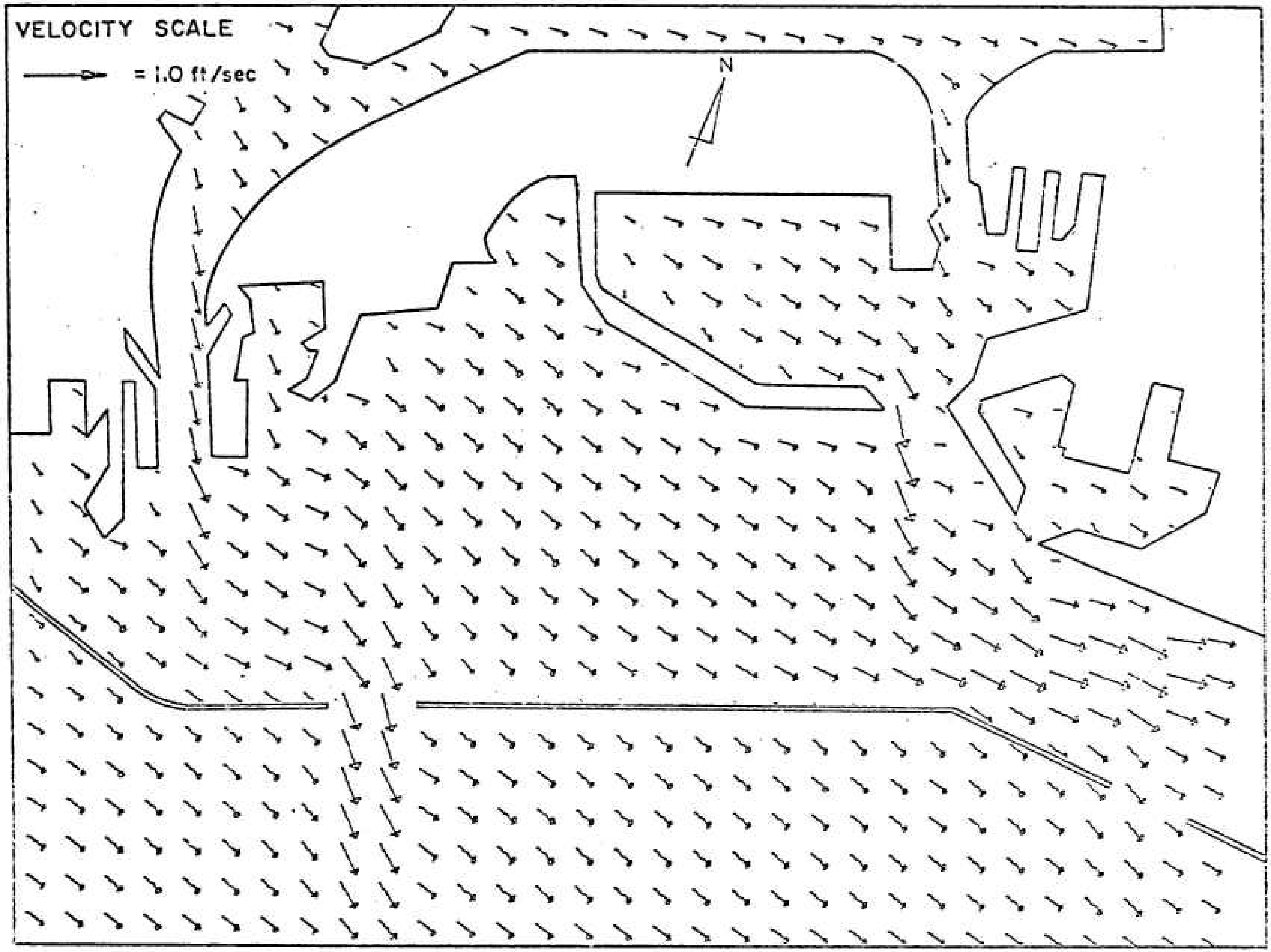

Figure 13a - Current Field at Hour 3.5, Wind Speed = 5 knots
Direction = 284.5°

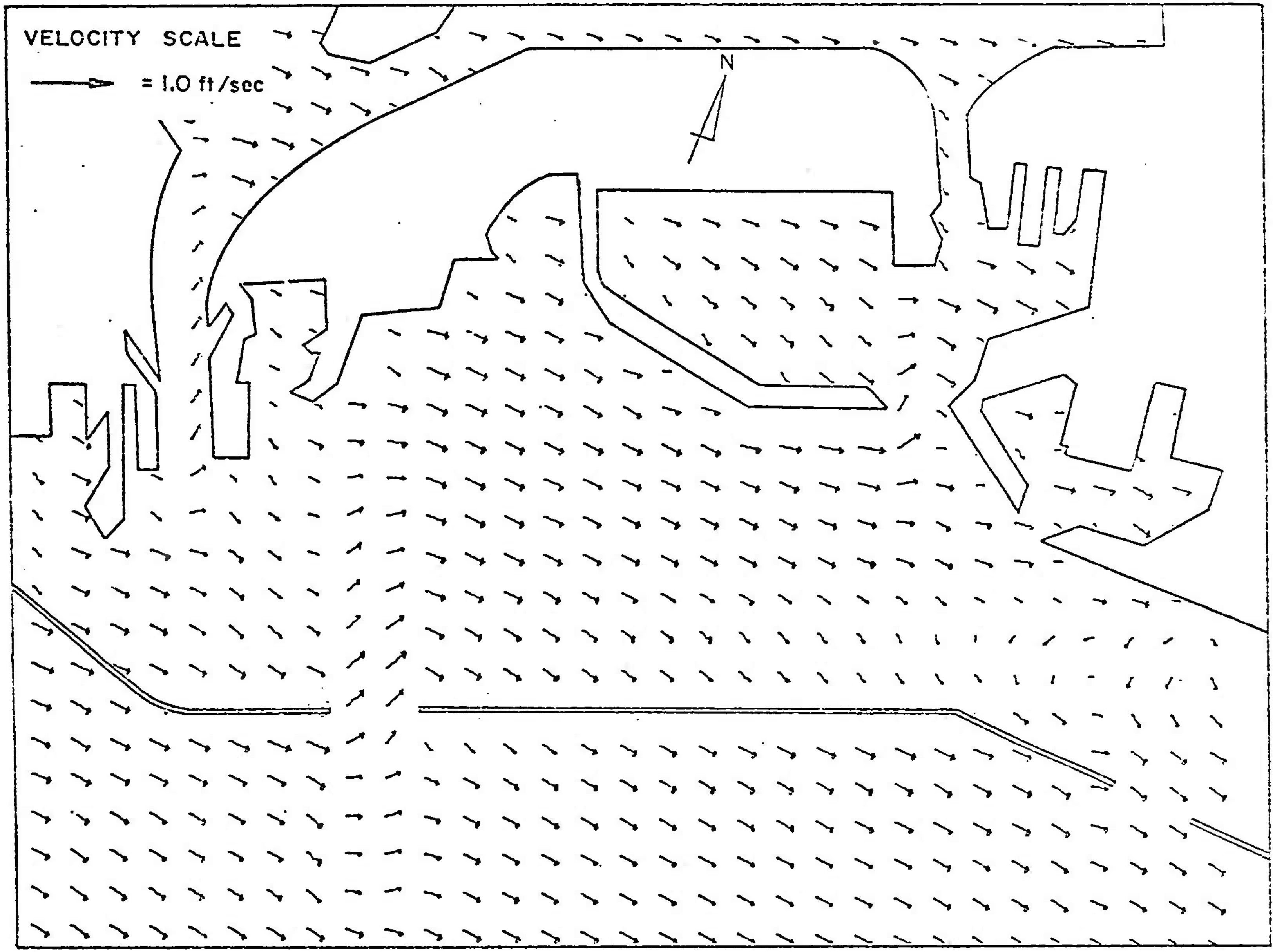

Figure 13b - Current Field at Hour 10.5, Wind Speed = 5 knots
Direction = 284.5°

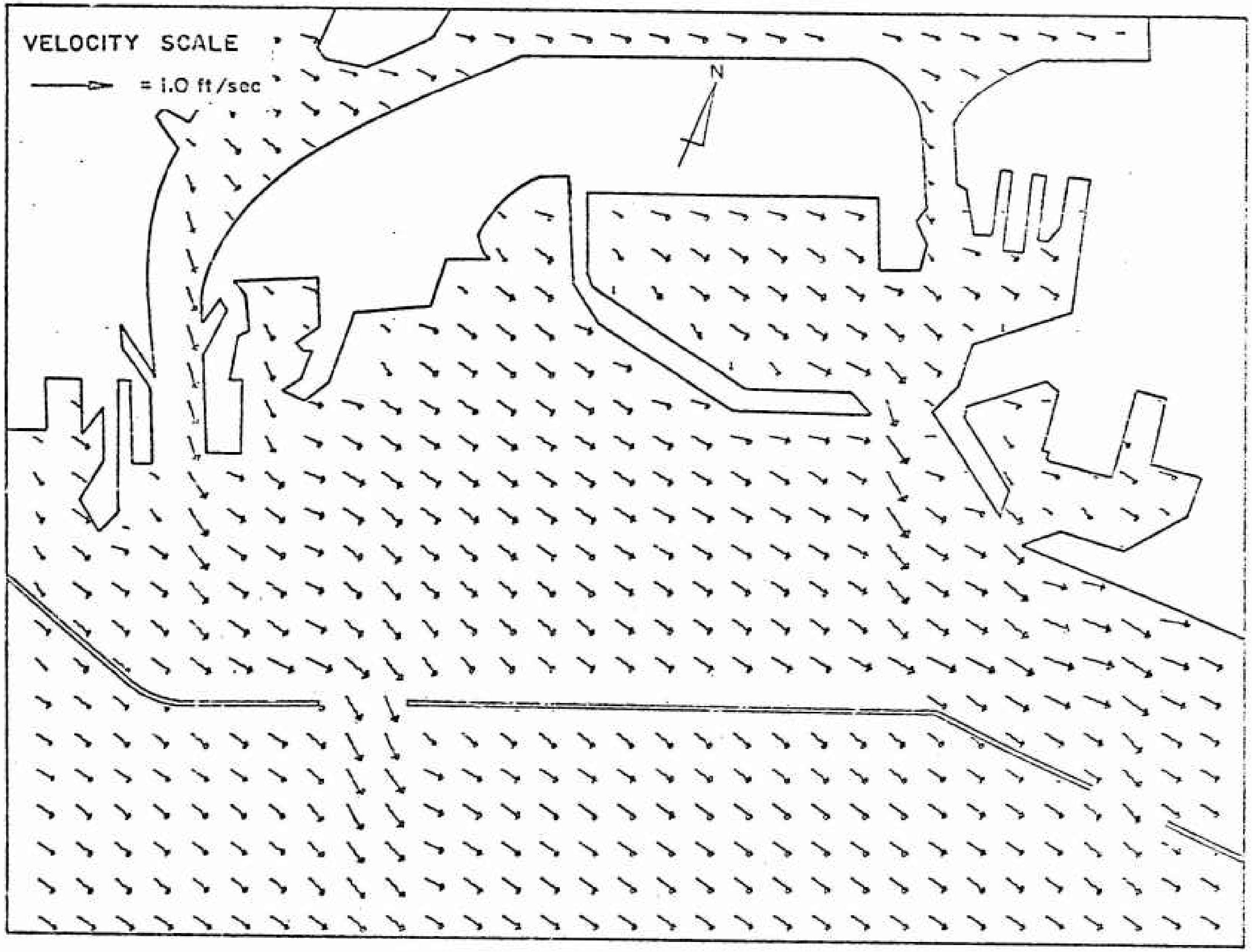

Figure 13c - Current Field at Hour 16, Wind Speed = 5 knots
Direction = 284.5°

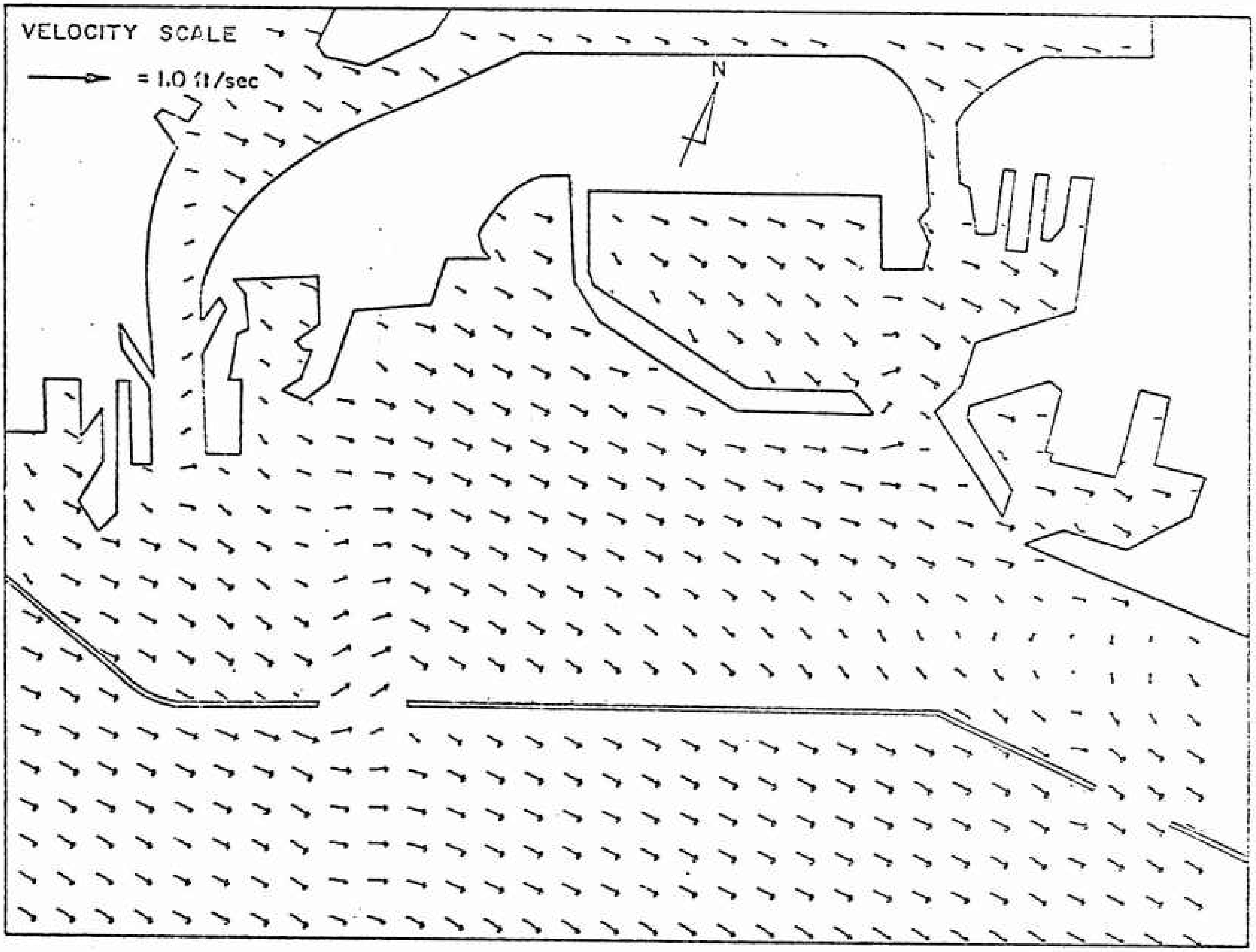

Figure 13d - Current Field at Hour 21.5, Wind Speed = 5 knots
Direction = 284.5°

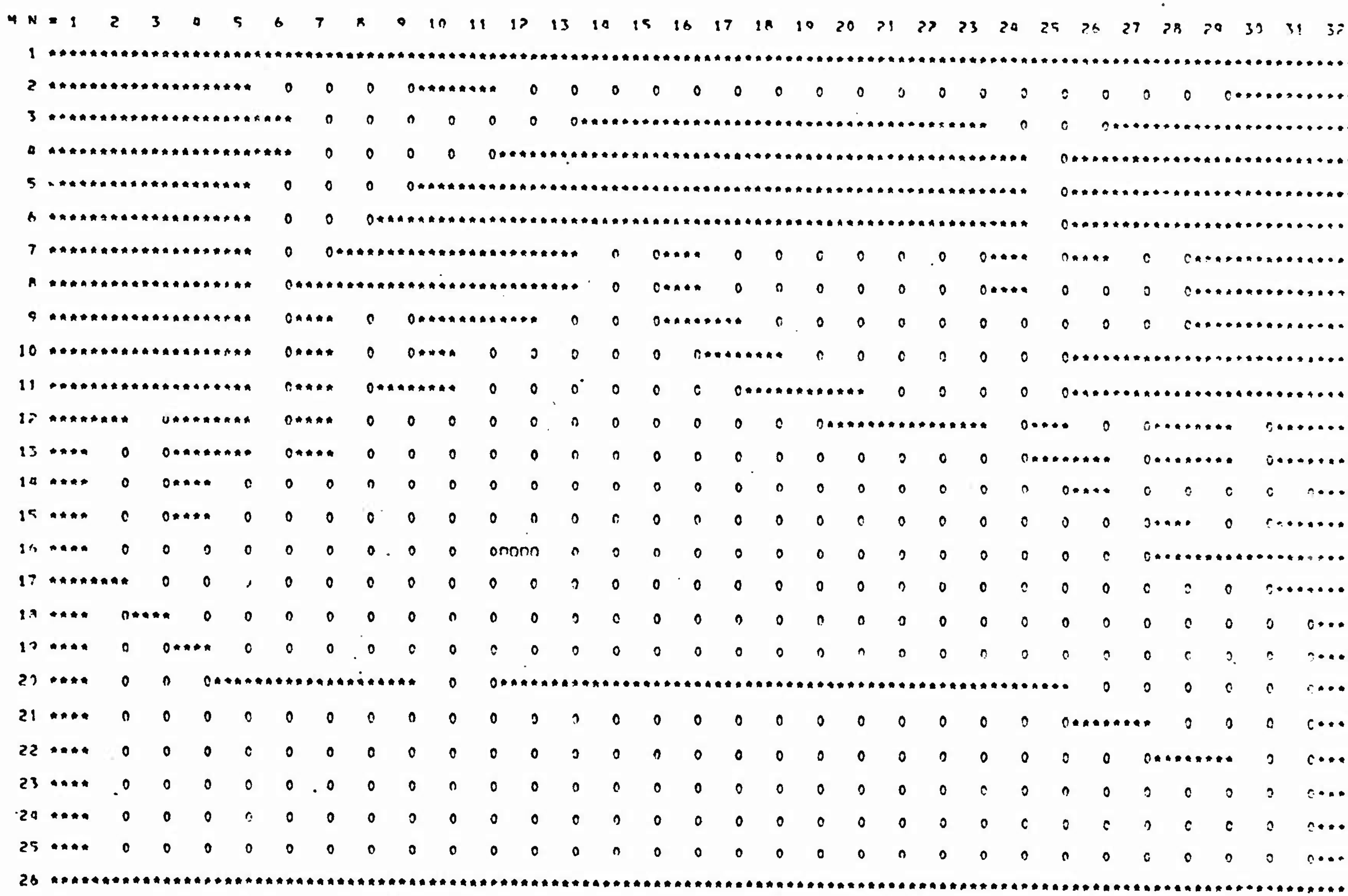

Figure 14 - Oil Spill Site at Hour 0

THICKNESS OF OILFILM IN CM/1000, AT END OF HOUR 18
OIL INSIDE THE BAY= 100000 GALLONS

M N =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	*	*	*	*	0	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*
3	*	*	*	*	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	0	0	0	*	*	*	*	*	*
4	*	*	*	*	*	*	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
5	*	*	*	*	*	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
6	*	*	*	*	*	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
7	*	*	*	*	*	0	0	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	*	0	0	*	*	*	*
8	*	*	*	*	*	0	*	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	0	0	0	*	*	*	*
9	*	*	*	*	*	0	*	0	0	*	*	*	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*
10	*	*	*	*	*	0	*	0	0	*	0	0	0	0	0	0	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*
11	*	*	*	*	*	0	*	0	*	*	0	0	0	0	0	0	0	*	*	*	0	0	0	0	0	*	*	*	*	*	*	*
12	*	*	0	*	*	0	*	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*	0	*	0	0	*	*	0	*	*
13	*	0	0	*	*	0	*	0	0	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	*	*	0	*	*
14	*	0	0	*	0	0	0	0	3	3	10	10	3	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	*
15	*	0	0	*	0	0	0	0	0	7	16	20	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	*	*
16	*	0	0	0	0	0	0	0	0	7	23	29	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*	*
17	*	*	0	0	0	0	0	0	0	7	23	26	20	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*
18	*	0	*	0	0	0	0	0	0	0	7	37	18	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
19	*	0	0	*	0	0	0	0	0	0	24	29	35	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
20	*	0	0	0	*	*	*	*	*	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	0	0	0	0	0	*
21	*	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	0	0	*
22	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	*
23	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
24	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
25	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
26	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Figure 15a - Spreading and Transport of Oil Slick, No Wind

THICKNESS OF OILFILM IN CM/1000, AT END OF HOUR 24
OIL INSIDE THE BAY= 100000 GALLONS

M N =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	*	*	*	*	0	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*
3	*	*	*	*	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	0	0	0	*	*	*	*	*	*
4	*	*	*	*	*	*	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
5	*	*	*	*	*	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
6	*	*	*	*	*	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
7	*	*	*	*	*	0	0	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	*	0	0	*	*	*	*
8	*	*	*	*	*	0	*	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	0	0	0	*	*	*	*
9	*	*	*	*	*	0	*	0	0	*	*	*	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*
10	*	*	*	*	*	0	*	0	0	*	0	0	0	0	0	0	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*
11	*	*	*	*	*	0	*	0	*	*	0	0	0	0	0	0	0	*	*	*	0	0	0	0	0	*	*	*	*	*	*	*
12	*	*	0	*	*	0	*	1	2	3	4	0	3	0	0	0	0	0	0	*	*	*	*	0	*	0	0	*	*	0	*	*
13	*	0	0	*	*	0	*	1	5	5	11	5	7	3	0	0	0	0	0	0	0	0	0	0	*	*	0	*	*	0	*	*
14	*	0	0	*	0	0	0	3	3	12	16	18	8	5	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	*
15	*	0	0	*	0	0	0	0	3	6	25	18	14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	*	*
16	*	0	0	0	0	0	0	0	1	6	17	26	12	3	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*	*
17	*	*	0	0	0	0	0	1	1	2	13	22	17	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*
18	*	0	*	0	0	0	0	0	2	1	7	17	23	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
19	*	0	0	*	0	0	0	0	0	1	0	14	14	12	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
20	*	0	0	0	*	*	*	*	*	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	0	0	0	0	0	*
21	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	0	0	*
22	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	*
23	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
24	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
25	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
26	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Figure 15b - Spreading and Transport of Oil Slick, No Wind

THICKNESS OF OILFILM IN CM/1000, AT END OF HOUR 30
OIL INSIDE THE BAY= 100000 GALLONS

M N =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	*	*	*	*	0	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*
3	*	*	*	*	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	0	0	0	*	*	*	*	*	*
4	*	*	*	*	*	*	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
5	*	*	*	*	*	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
6	*	*	*	*	*	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
7	*	*	*	*	*	0	0	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	*	0	0	*	*	*	*
8	*	*	*	*	*	0	*	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	0	0	0	*	*	*	*
9	*	*	*	*	*	0	*	0	0	*	*	*	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*
10	*	*	*	*	*	0	*	0	0	*	0	0	0	0	0	0	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*
11	*	*	*	*	*	0	*	0	*	*	0	0	0	0	0	0	0	*	*	*	0	0	0	0	0	*	*	*	*	*	*	*
12	*	*	0	*	*	0	*	1	2	2	1	0	1	0	0	0	0	0	0	*	*	*	*	0	*	0	0	*	*	0	*	*
13	*	0	0	*	*	0	*	1	3	3	4	2	2	1	0	0	0	0	0	0	0	0	0	0	*	*	0	*	*	0	*	*
14	*	0	0	*	0	0	0	2	2	4	9	8	5	3	1	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	*
15	*	0	0	*	0	0	1	1	2	7	18	15	10	3	1	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	*	*
16	*	0	0	0	0	0	0	1	1	8	20	22	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*	*
17	*	*	0	0	0	0	0	0	1	5	18	23	11	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*
18	*	0	*	0	0	0	0	0	0	3	14	25	20	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
19	*	0	0	*	0	0	0	0	0	0	18	26	18	11	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
20	*	0	0	0	*	*	*	*	*	6	6	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	0	0	0	0	0	*
21	*	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	0	0	*
22	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	*
23	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
24	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
25	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
26	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Figure 15c - Spreading and Transport of Oil Slick, No Wind

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THICKNESS OF OILFILM IN CM/1000, AT END OF HOUR   36
 OIL INSIDE THE BAY=    100000 GALLONS

M N=   1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32
  1 ********************************************************************************************************************************
  2 ********************   0   0   0   0********   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0************
  3 ************************   0   0   0   0   0   0   0****************************************   0   0   0************************
  4 ************************   0   0   0   0   0****************************************************   0****************************
  5 ********************   0   0   0   0************************************************************   0****************************
  6 ********************   0   0   0****************************************************************   0****************************
  7 ********************   0   0************************   0   0****   0   0   0   0   0   0   0****   0****   0   0****************
  8 ********************   0****************************   0   0****   0   0   0   0   0   0   0****   0   0   0   0****************
  9 ********************   0****   0   0************   0   0   0********   0   0   0   0   0   0   0   0   0   0   0****************
 10 ********************   0****   0   0****   0   0   0   0   0   0********   0   0   0   0   0   0   0****************************
 11 ********************   0****   0********   0   1   0   0   0   0   0************   0   0   0   0   0****************************
 12 ********   0********   0****   2   3   5   4   1   2   0   0   0   0   0   0****************   0****   0   0********   0********
 13 ****   0   0********   0****   1   5   8   8   3   3   2   1   0   0   0   0   0   0   0   0   0********   0********   0********
 14 ****   0   0****   0   1   1   2   3   9  15   9   6   4   1   0   0   0   0   0   0   0   0   0   0****   0   0   0   0   0****
 15 ****   0   0****   0   0   1   0   2  10  15  17  11   4   1   0   0   0   0   0   0   0   0   0   0   0   0****   0   0********
 16 ****   0   0   0   0   0   0   0   0   2  15  14  12   5   1   0   0   0   0   0   0   0   0   0   0   0   0********************
 17 ********   0   0   0   0   0   0   1   4   8  23  10   4   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0********
 18 ****   0****   0   0   0   0   0   0   4  12  20  19   2   1   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0****
 19 ****   0   0****   0   0   0   0   4   4  10  23  14   7   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0****
 20 ****   0   0   0********************   4   0********************************************************   0   0   0   0   0   0****
 21 ****   0   0   0   0   0   0   0   1   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0********   0   0   0   0****
 22 ****   0   0   0   0   0   0   1   2   4   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0********   0   0****
 23 ****   0   0   0   0   0   0   0   3   2   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0****
 24 ****   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0****
 25 ****   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0****
 26 ********************************************************************************************************************************
```

Figure 15d - Spreading and Transport of Oil Slick, No Wind

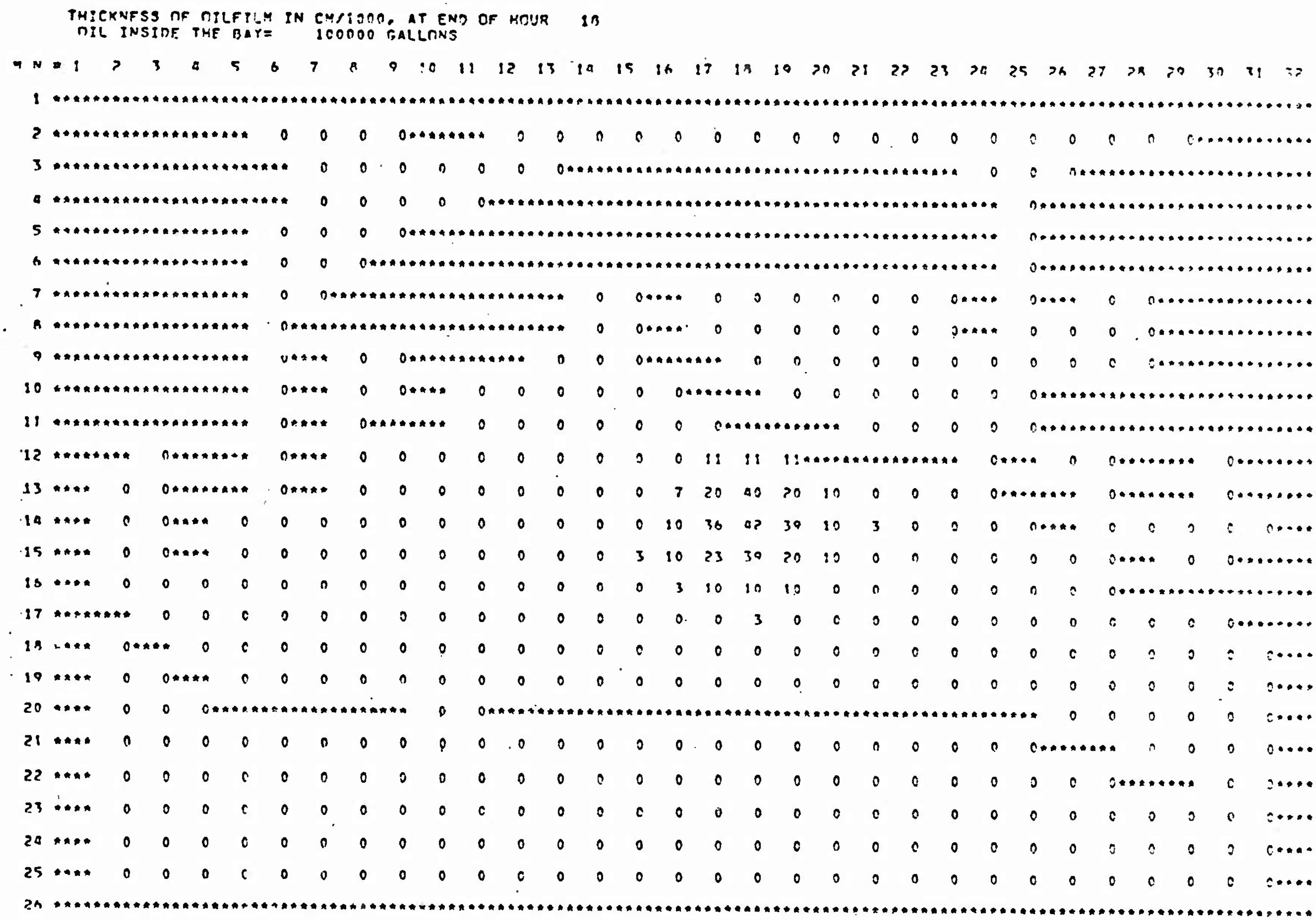


Figure 16a - Spreading and Transport of Oil Slick, Wind Speed = 2 knots
Direction = 225°

THICKNESS OF OILFILM IN CM/1000, AT END OF HOUR 24
OIL INSIDE THE BAY= 100000 GALLONS

M \ N =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	*	*	*	*	0	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*
3	*	*	*	*	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	0	0	0	*	*	*	*	*	*
4	*	*	*	*	*	*	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
5	*	*	*	*	*	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
6	*	*	*	*	*	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
7	*	*	*	*	*	0	0	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	*	0	0	*	*	*	*
8	*	*	*	*	*	0	*	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	0	0	0	*	*	*	*
9	*	*	*	*	*	0	*	0	0	*	*	*	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*
10	*	*	*	*	*	0	*	0	0	*	0	0	0	0	0	0	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*
11	*	*	*	*	*	0	*	0	*	*	0	0	0	0	0	0	0	*	*	*	0	0	0	1	0	*	*	*	*	*	*	*
12	*	*	0	*	*	0	*	0	0	0	0	0	0	0	0	0	4	33	43	*	*	*	*	1	*	0	0	*	*	0	*	*
13	*	0	0	*	*	0	*	0	0	0	0	0	0	0	0	0	3	21	68	44	44	22	17	6	*	*	0	*	*	0	*	*
14	*	0	0	*	0	0	0	0	0	0	0	0	0	0	0	1	3	7	18	32	9	14	5	0	0	*	0	0	0	0	0	*
15	*	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	3	3	0	0	0	0	0	0	*	0	0	*	*
16	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	*	*	*	*	*
17	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*
18	*	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
19	*	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
20	*	0	0	0	*	*	*	*	*	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	0	0	0	0	0	*
21	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	0	0	*
22	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	*
23	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
24	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
25	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
26	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Figure 16b - Spreading and Transport of Oil Slick, Wind Speed = 2 knots
Direction = 225°

THICKNESS OF OILFILM IN CM/1000, AT END OF HOUR 30
OIL INSIDE THE BAY= 100000 GALLONS

M N =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	*	*	*	*	0	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*
3	*	*	*	*	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	0	0	0	*	*	*	*	*	*
4	*	*	*	*	*	*	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
5	*	*	*	*	*	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
6	*	*	*	*	*	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
7	*	*	*	*	*	0	0	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	*	0	0	*	*	*	*
8	*	*	*	*	*	0	*	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	0	0	0	*	*	*	*
9	*	*	*	*	*	0	*	0	0	*	*	*	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*
10	*	*	*	*	*	0	*	0	0	*	0	0	0	0	0	0	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*
11	*	*	*	*	*	0	*	0	*	*	0	0	0	0	0	0	0	*	*	*	0	0	0	1	0	*	*	*	*	*	*	*
12	*	*	0	*	*	0	*	0	0	0	0	0	0	0	0	0	0	35	35	*	*	*	*	2	*	0	0	*	*	0	*	*
13	*	0	0	*	*	0	*	0	0	0	0	0	0	0	0	0	0	1	37	25	43	54	34	20	*	*	0	*	*	0	*	*
14	*	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	23	21	19	9	8	*	0	0	0	0	0	*
15	*	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	11	7	5	1	*	0	0	*	*
16	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1	0	*	*	*	*	*
17	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*
18	*	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
19	*	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
20	*	0	0	0	*	*	*	*	*	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	0	0	0	0	0	*
21	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	0	0	*
22	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	*
23	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
24	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
25	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
26	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Figure 16c - Spreading and Transport of Oil Slick, Wind Speed = 2 knots
Direction = 225°

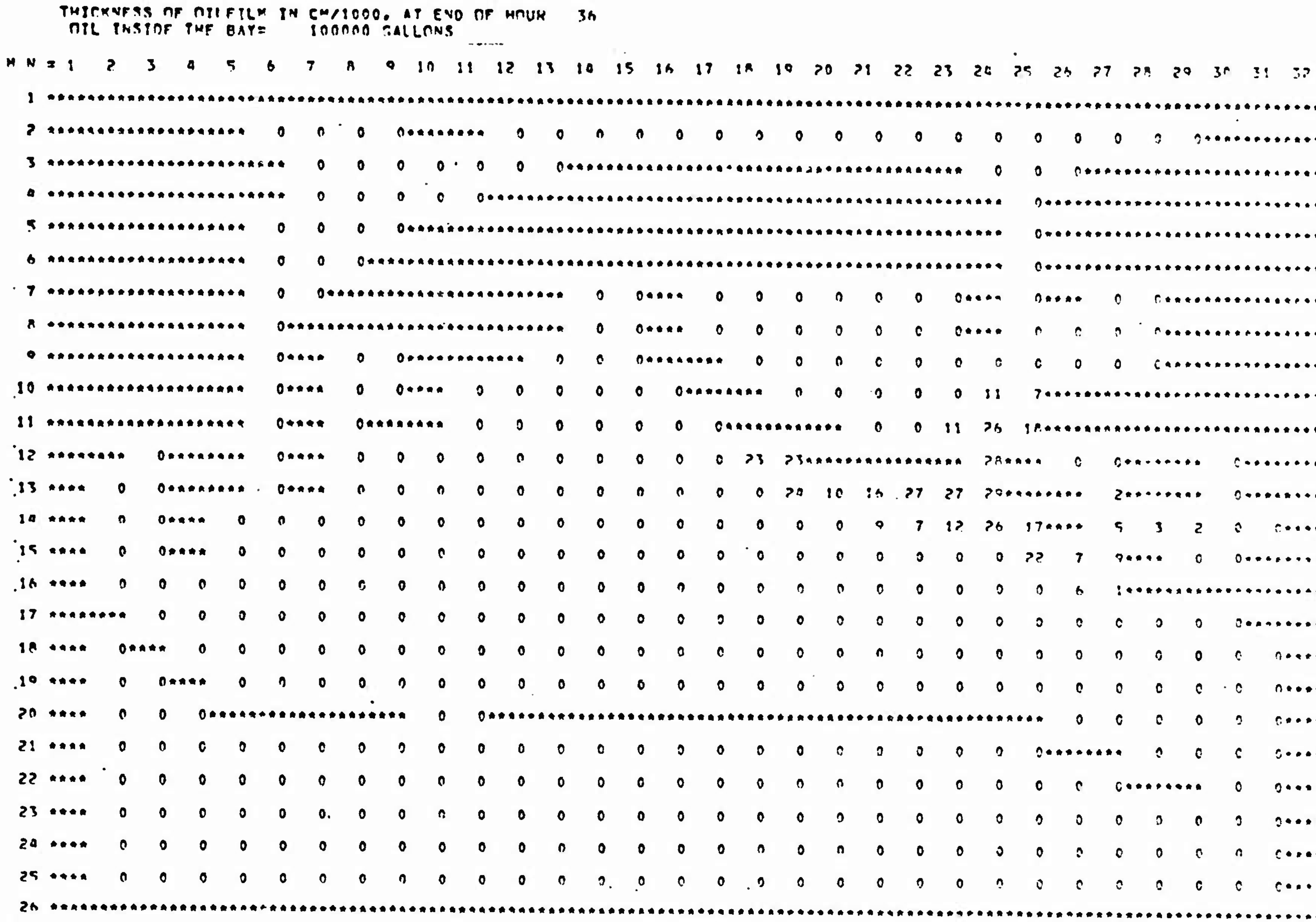


Figure 16d - Spreading and Transport of Oil Slick, Wind Speed = 2 knots
Direction = 225°

THICKNESS OF OILFILM IN CM/1000, AT END OF HOUR 18
OIL INSIDE THE BAY= 100000 GALLONS

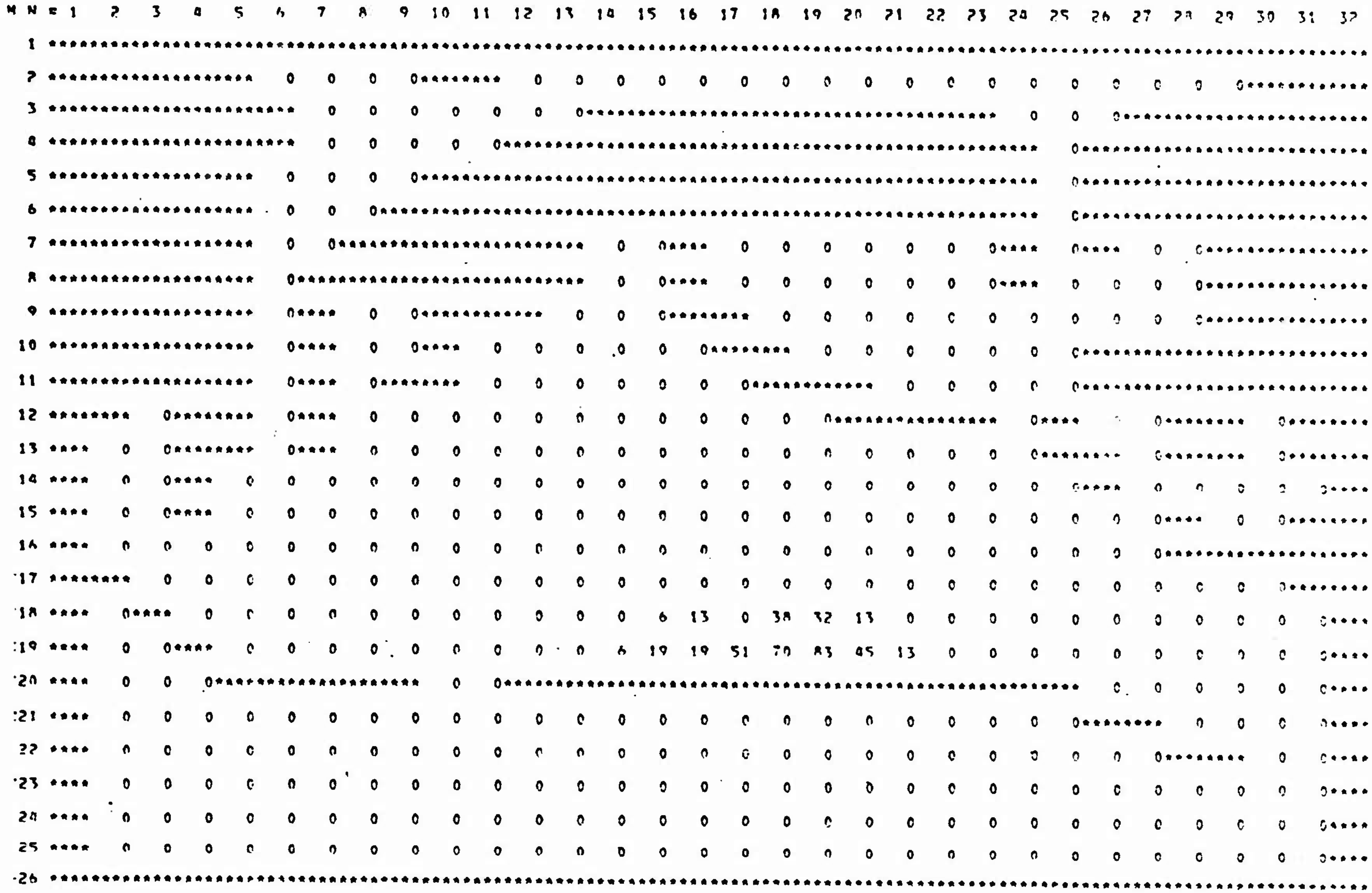


Figure 17a - Spreading and Transport of Oil Slick, Wind Speed = 5 knots
Direction = 284.5°

THICKNESS OF OILFILM IN CM/1000, AT END OF HOUR 24
OIL INSIDE THE BAY= 100000 GALLONS

M N =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
2	****	****	****	****	****	0	0	0	0	****	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****	****
3	****	****	****	****	****	****	0	0	0	0	0	0	0	****	****	****	****	****	****	****	****	****	****	0	0	0	****	****	****	****	****	****
4	****	****	****	****	****	****	0	0	0	0	0	****	****	****	****	****	****	****	****	****	****	****	****	****	0	****	****	****	****	****	****	****
5	****	****	****	****	****	0	0	0	0	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	0	****	****	****	****	****	****	****
6	****	****	****	****	****	0	0	0	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	0	****	****	****	****	****	****	****
7	****	****	****	****	****	0	0	****	****	****	****	****	****	0	0	****	0	0	0	0	0	0	0	****	0	****	0	0	****	****	****	****
8	****	****	****	****	****	0	****	****	****	****	****	****	****	0	0	****	0	0	0	0	0	0	0	****	0	0	0	0	****	****	****	****
9	****	****	****	****	****	0	****	0	0	****	****	****	0	0	0	****	****	0	0	0	0	0	0	0	0	0	0	0	****	****	****	****
10	****	****	****	****	****	0	****	0	0	****	0	0	0	0	0	0	****	****	0	0	0	0	0	0	0	****	****	****	****	****	****	****
11	****	****	****	****	****	0	****	0	****	****	0	0	0	0	0	0	0	****	****	****	0	0	0	0	0	****	****	****	****	****	****	****
12	****	****	0	****	****	0	****	0	0	0	0	0	0	0	0	0	0	0	0	****	****	****	****	0	****	0	0	****	****	0	****	****
13	****	0	0	****	****	0	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****	0	****	****	0	****	****
14	****	0	0	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	0	0	0	0	0	****
15	****	0	0	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	0	0	****	****
16	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****	****	****	****
17	****	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****
18	****	0	****	0	0	0	0	0	0	0	0	0	0	0	2	5	6	16	18	30	19	6	0	0	0	0	0	0	0	0	0	****
19	****	0	0	****	0	0	0	0	0	0	0	0	0	2	6	13	27	40	64	67	56	25	6	0	0	0	0	0	0	0	0	****
20	****	0	0	0	****	****	****	****	****	0	0	****	****	****	****	****	****	****	****	****	****	****	****	****	****	0	0	0	0	0	0	****
21	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****	0	0	0	0	****
22	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****	0	0	****
23	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****
24	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****
25	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****
26	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****

Figure 17b - Spreading and Transport of Oil Slick, Wind Speed = 5 knots
Direction = 284.5°

THICKNESS OF OILFILM IN CM/1000, AT END OF HOUR 30
OIL INSIDE THE BAY= 100000 GALLONS

M N =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	*	*	*	*	0	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*
3	*	*	*	*	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	0	0	0	*	*	*	*	*	*
4	*	*	*	*	*	*	0	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
5	*	*	*	*	*	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
6	*	*	*	*	*	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*
7	*	*	*	*	*	0	0	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	*	0	0	*	*	*	*
8	*	*	*	*	*	0	*	*	*	*	*	*	*	0	0	*	0	0	0	0	0	0	0	*	0	0	0	0	*	*	*	*
9	*	*	*	*	*	0	*	0	0	*	*	*	0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*
10	*	*	*	*	*	0	*	0	0	*	0	0	0	0	0	0	*	*	0	0	0	0	0	0	0	*	*	*	*	*	*	*
11	*	*	*	*	*	0	*	0	*	*	0	0	0	0	0	0	0	*	*	*	0	0	0	0	0	*	*	*	*	*	*	*
12	*	*	0	*	*	0	*	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*	0	*	0	0	*	*	0	*	*
13	*	0	0	*	*	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	*	*	0	*	*
14	*	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	*
15	*	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	*	*
16	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*	*
17	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*
18	*	0	*	0	0	0	0	0	0	0	0	0	0	0	2	3	7	11	18	21	18	14	6	2	0	0	0	0	0	0	0	*
19	*	0	0	*	0	0	0	0	0	0	0	0	0	2	5	12	22	36	49	57	53	39	22	8	2	0	0	0	0	0	0	*
20	*	0	0	0	*	*	*	*	*	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	0	0	0	0	0	*
21	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	0	0	*
22	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	0	0	*
23	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
24	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
25	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*
26	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Figure 17c - Spreading and Transport of Oil Slick, Wind Speed = 5 knots
Direction = 284.5°

THICKNESS OF OILFILM IN CM/1000, AT END OF HOUR 36
OIL INSIDE THE BAY= 100000 GALLONS

M N =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
2	****	****	****	****	****	0	0	0	0	****	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****	****
3	****	****	****	****	****	****	0	0	0	0	0	0	0	****	****	****	****	****	****	****	****	****	****	0	0	0	****	****	****	****	****	****
4	****	****	****	****	****	****	0	0	0	0	0	****	****	****	****	****	****	****	****	****	****	****	****	****	0	****	****	****	****	****	****	****
5	****	****	****	****	****	0	0	0	0	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	0	****	****	****	****	****	****	****
6	****	****	****	****	****	0	0	0	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	0	****	****	****	****	****	****	****
7	****	****	****	****	****	0	0	****	****	****	****	****	****	0	0	****	0	0	0	0	0	0	0	****	0	****	0	0	****	****	****	****
8	****	****	****	****	****	0	****	****	****	****	****	****	****	0	0	****	0	0	0	0	0	0	0	****	0	0	0	0	****	****	****	****
9	****	****	****	****	****	0	****	0	0	****	****	****	0	0	0	****	****	0	0	0	0	0	0	0	0	0	0	0	****	****	****	****
10	****	****	****	****	****	0	****	0	0	****	0	0	0	0	0	0	****	****	0	0	0	0	0	0	0	****	****	****	****	****	****	****
11	****	****	****	****	****	0	****	0	****	****	0	0	0	0	0	0	0	****	****	****	0	0	0	0	0	****	****	****	****	****	****	****
12	****	****	0	****	****	0	****	0	0	0	0	0	0	0	0	0	0	0	0	****	****	****	****	0	****	0	0	****	****	0	****	****
13	****	0	0	****	****	0	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****	0	****	****	0	****	****
14	****	0	0	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	0	0	0	0	0	****
15	****	0	0	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	0	0	****	****
16	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****	****	****	****
17	****	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****
18	****	0	****	0	0	0	0	0	0	0	0	0	0	0	1	3	0	6	11	15	19	18	14	9	2	0	0	0	0	0	0	****
19	****	0	0	****	0	0	0	0	0	0	0	0	1	2	5	5	10	17	32	44	52	51	42	25	11	4	0	0	0	0	0	****
20	****	0	0	0	****	****	****	****	****	0	0	****	****	****	****	****	****	****	****	****	****	****	****	****	****	2	2	1	0	0	0	****
21	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****	1	1	0	0	****
22	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****	****	0	0	****
23	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****
24	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****
25	****	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	****
26	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****

Figure 17d - Spreading and Transport of Oil Slick, Wind Speed = 5 knots
Direction = 284.5°

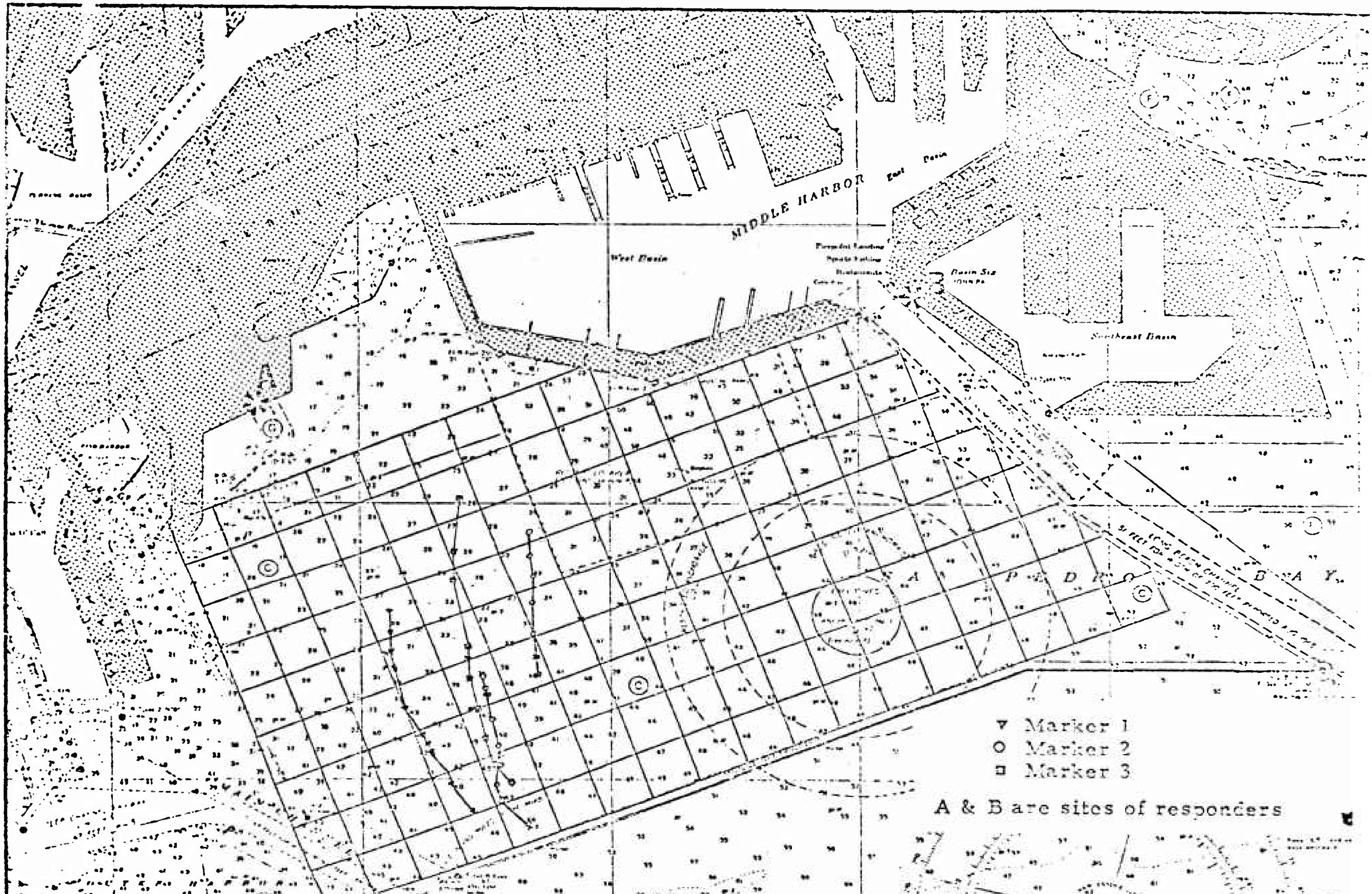


Figure 18. Field Traces of Cardboard Marker
October 5, 1973

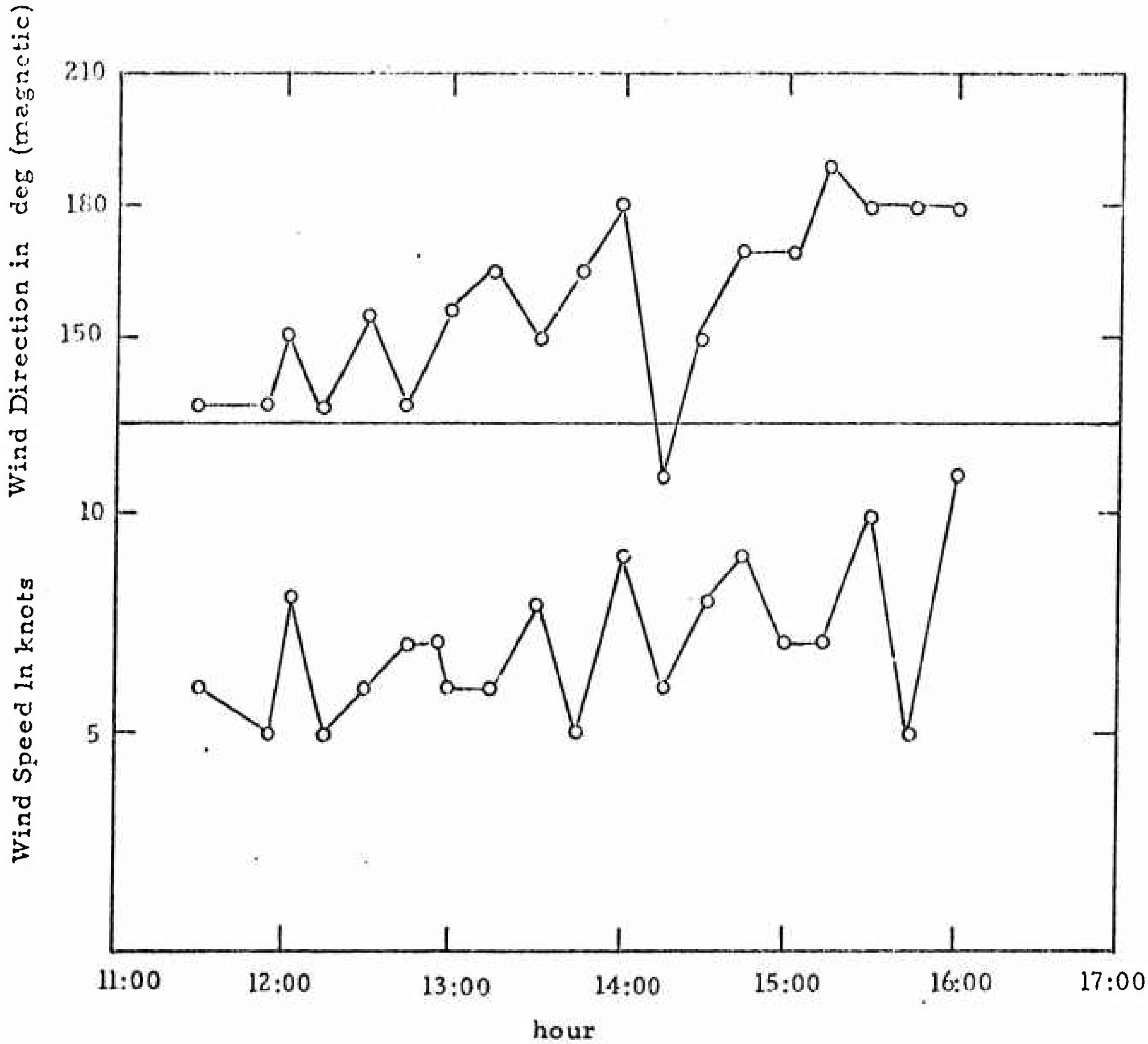


Figure 19. Records of Wind Collected on October 5, 1973

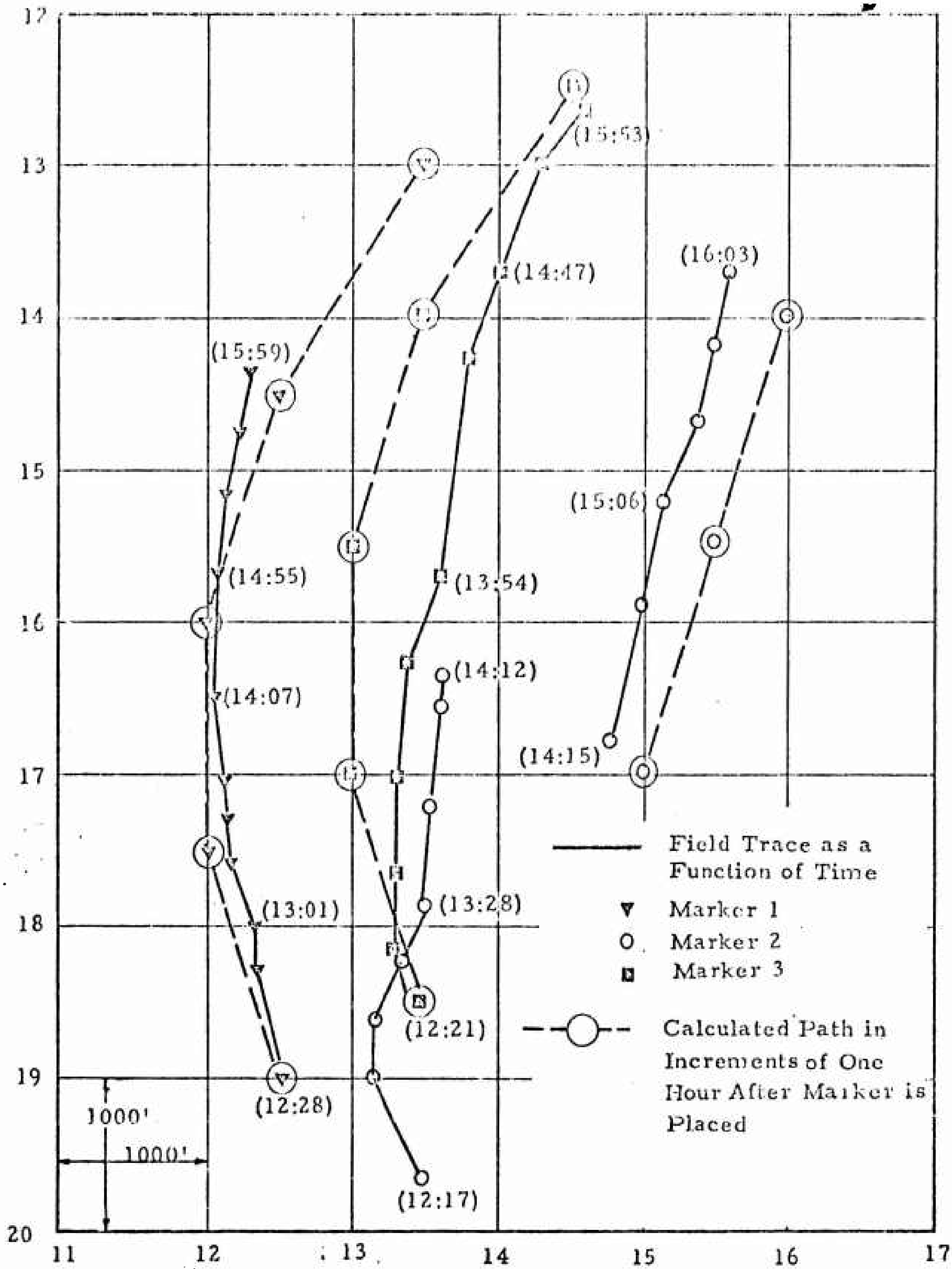


Figure 20. Calculated Paths and Field Traces of Markers Test 1 - October 5, 1973

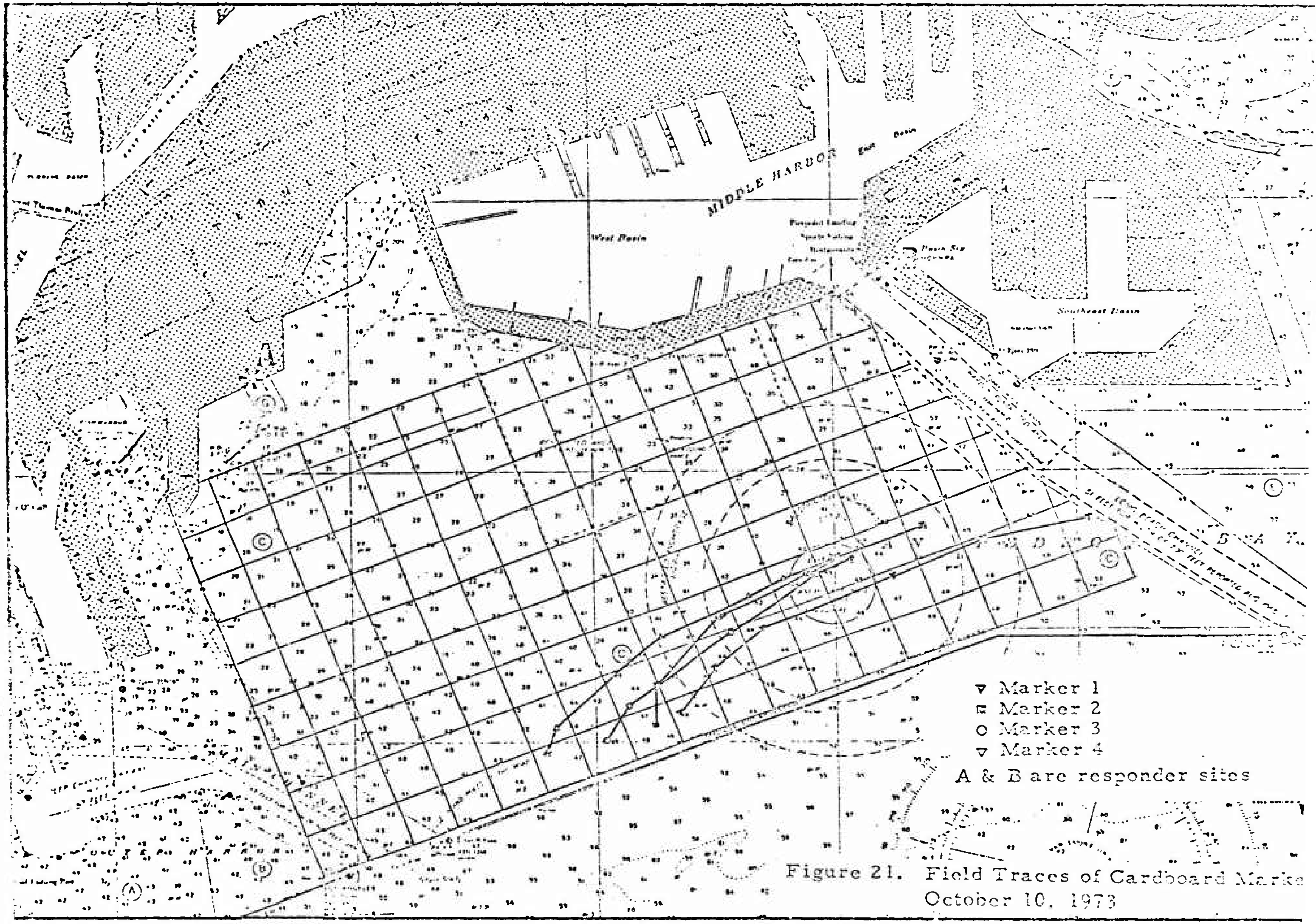


Figure 21. Field Traces of Cardboard Marke
October 10, 1973

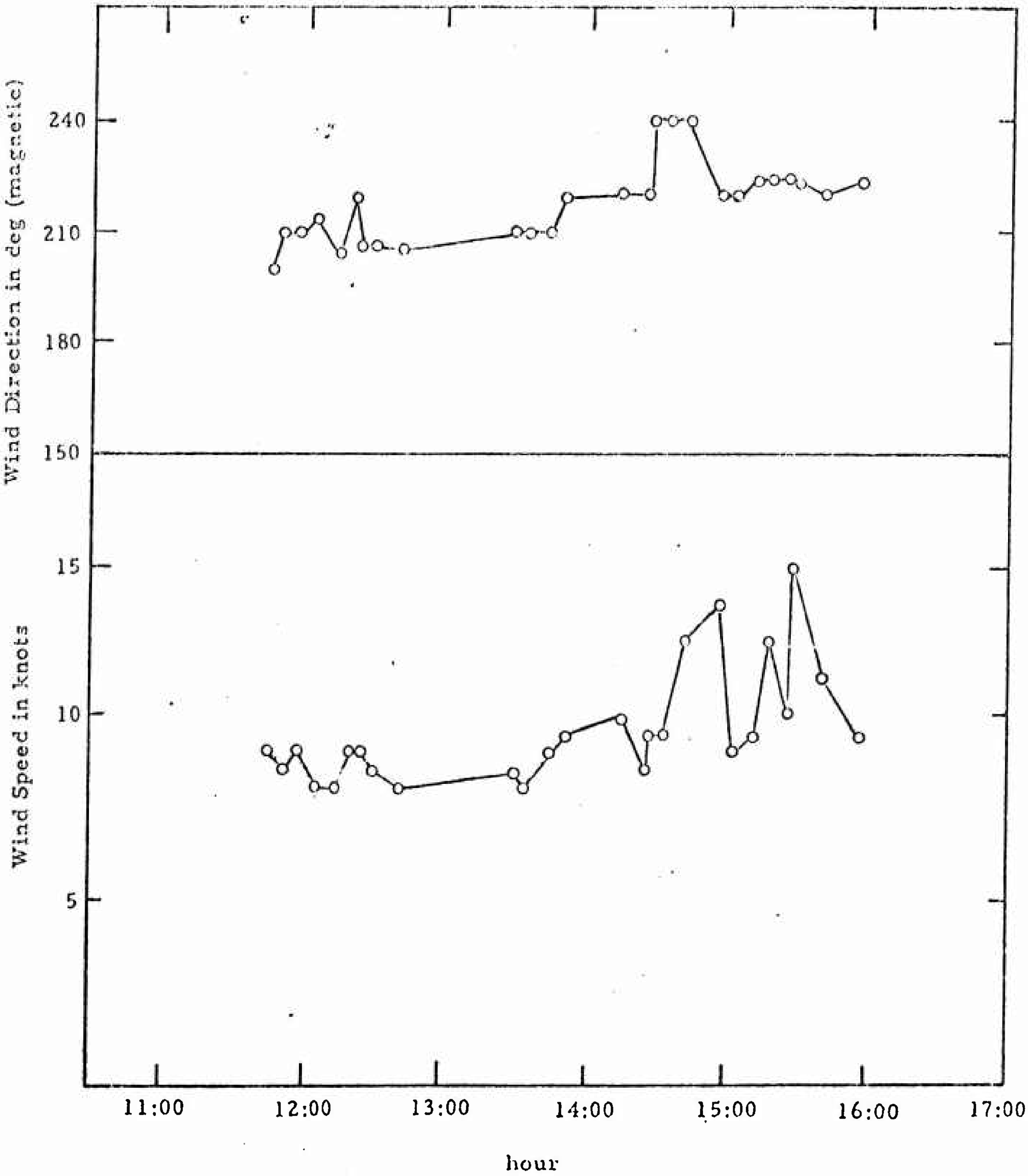


Figure 22. Record of Wind Collected on October 10, 1973

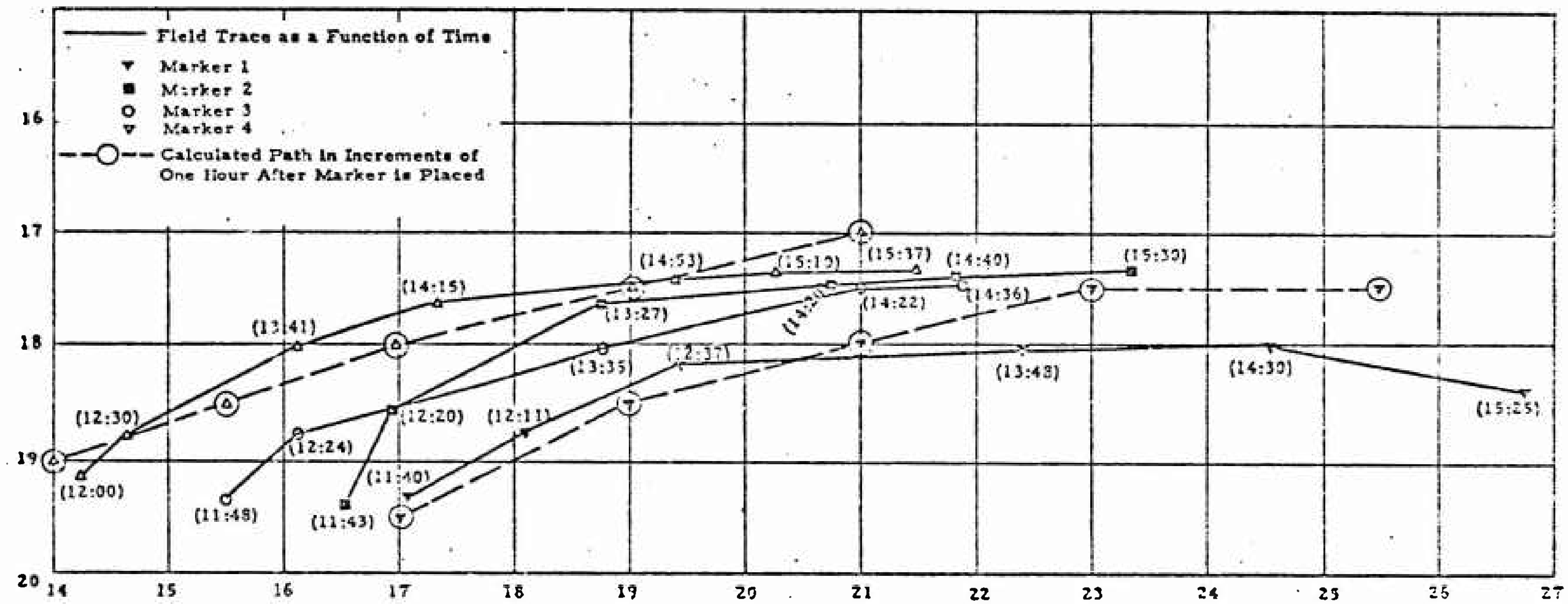
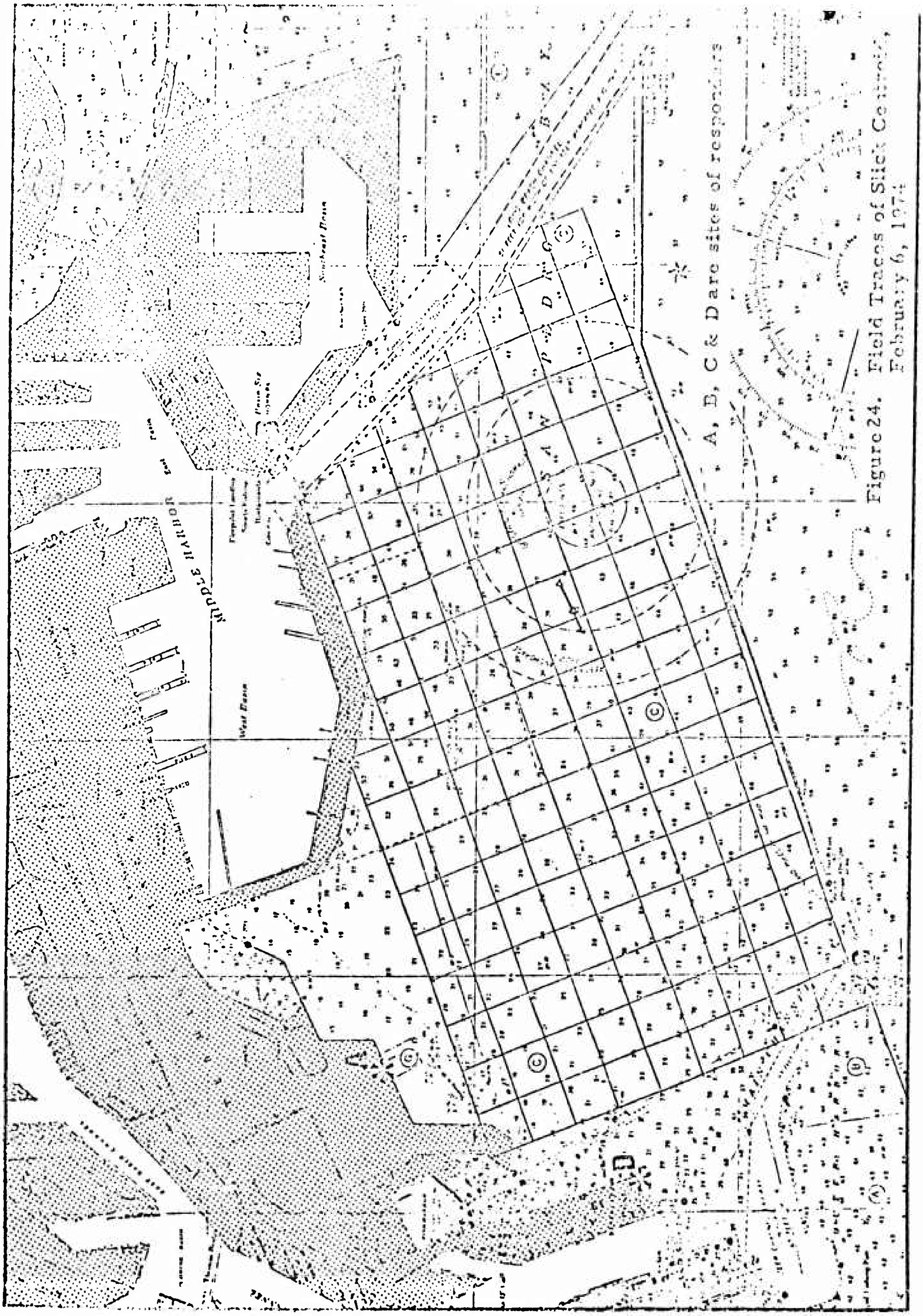


Figure 23. Calculated Paths and Field Traces of Markers - Test 2, October 10, 1973



A, B, C & D are sites of respondents

Figure 24. Field Traces of Slick Contours, February 6, 1974

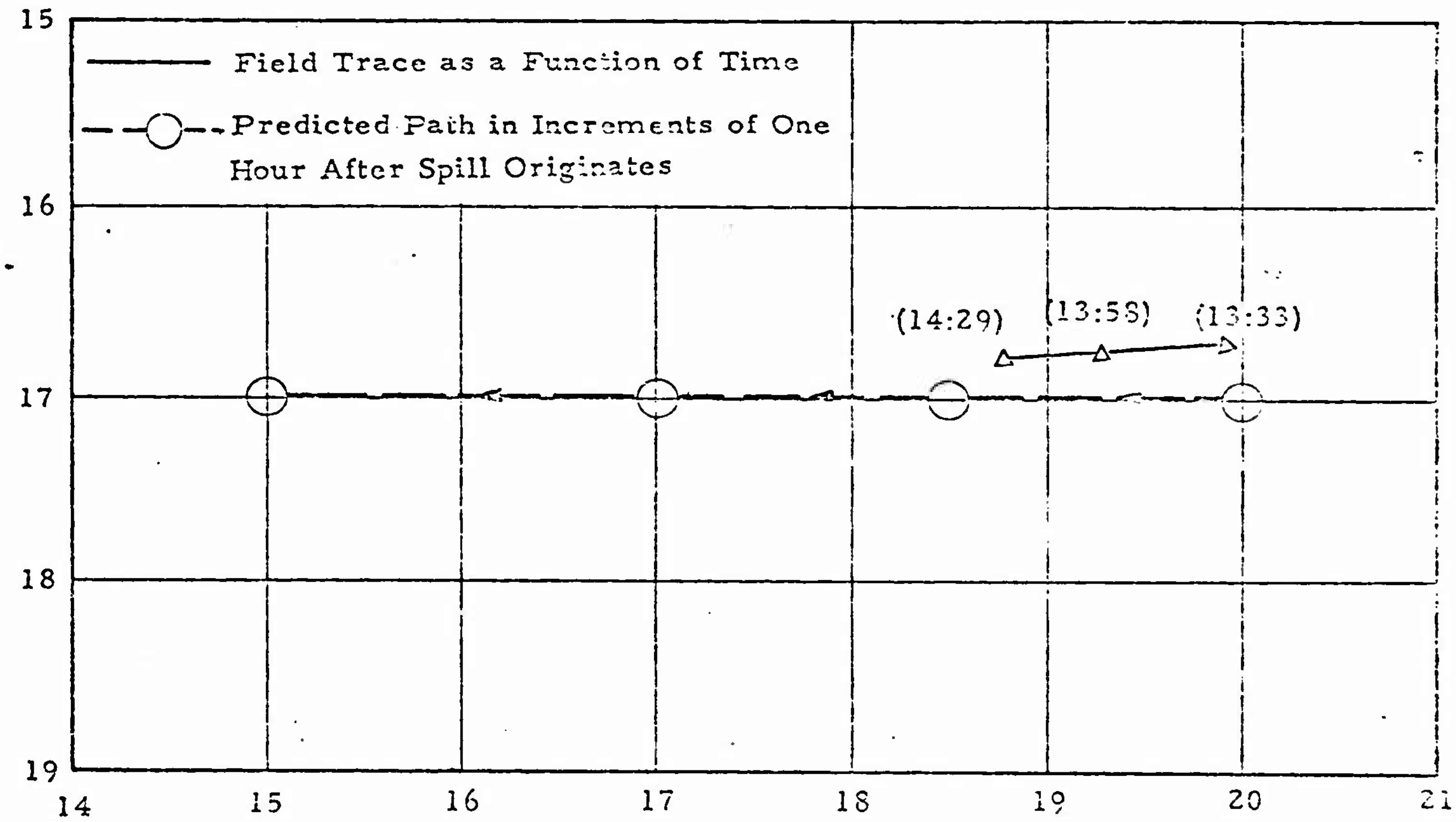
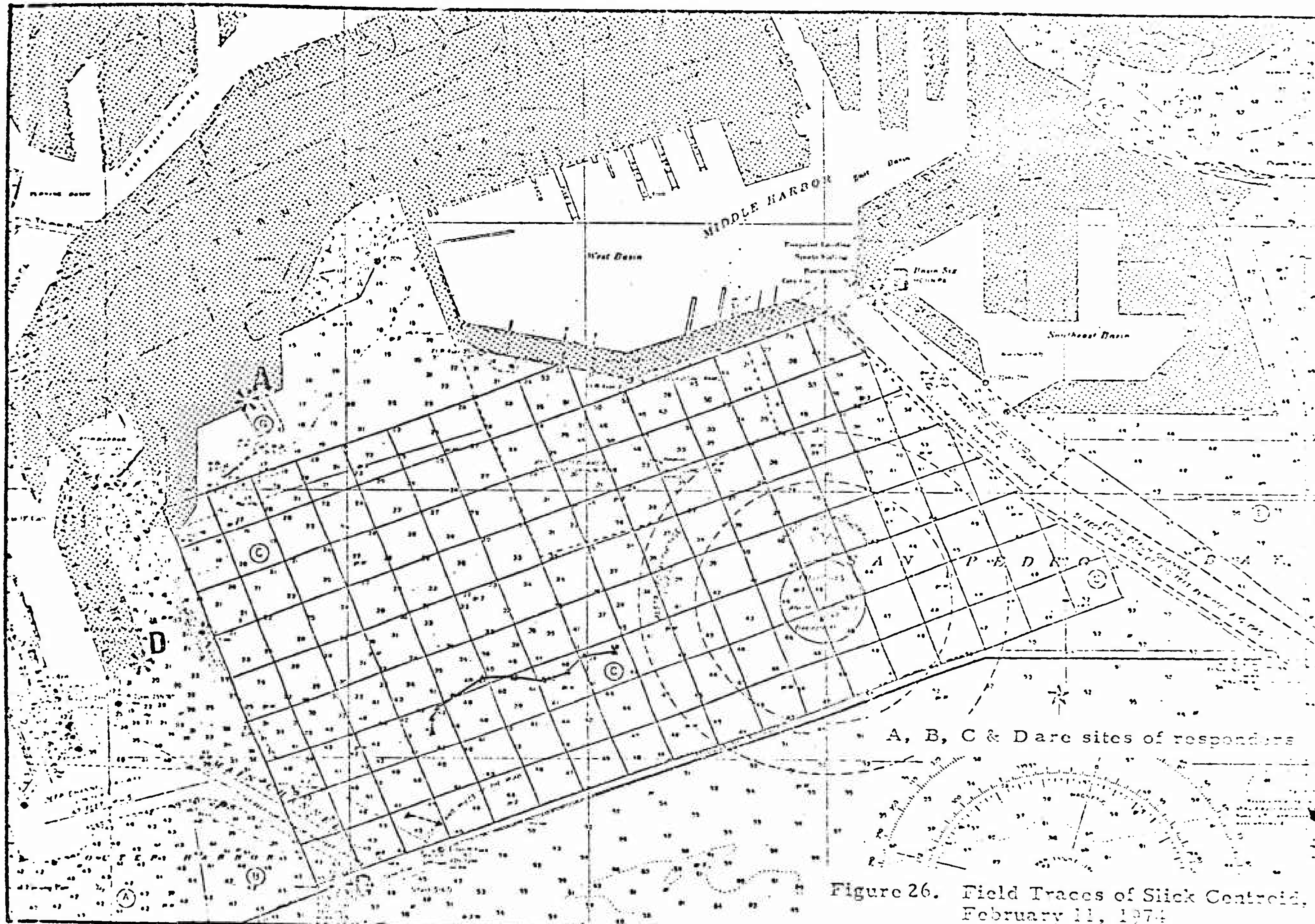


Figure 25. Predicted Path and Field Traces of Slick Centroid
Test 3 - February 6, 1974



A, B, C & D are sites of responders

Figure 26. Field Traces of Slick Centroid, February 11, 1974

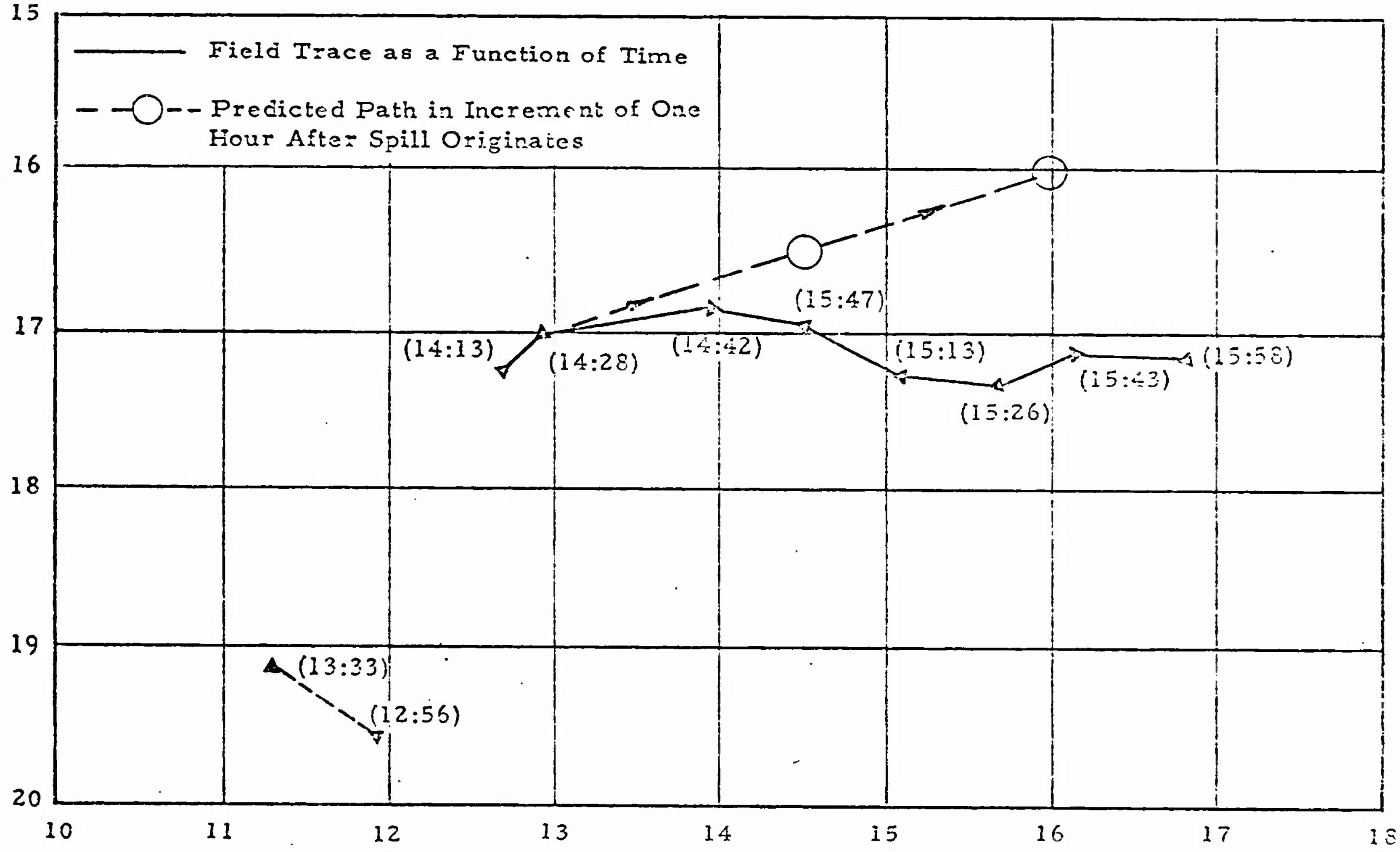


Figure 27. Predicted Path and Field Traces of Slick Centroid - Test 4 - Feb. 11, 1974 (No Wind Drift Deflection Considered in Prediction)

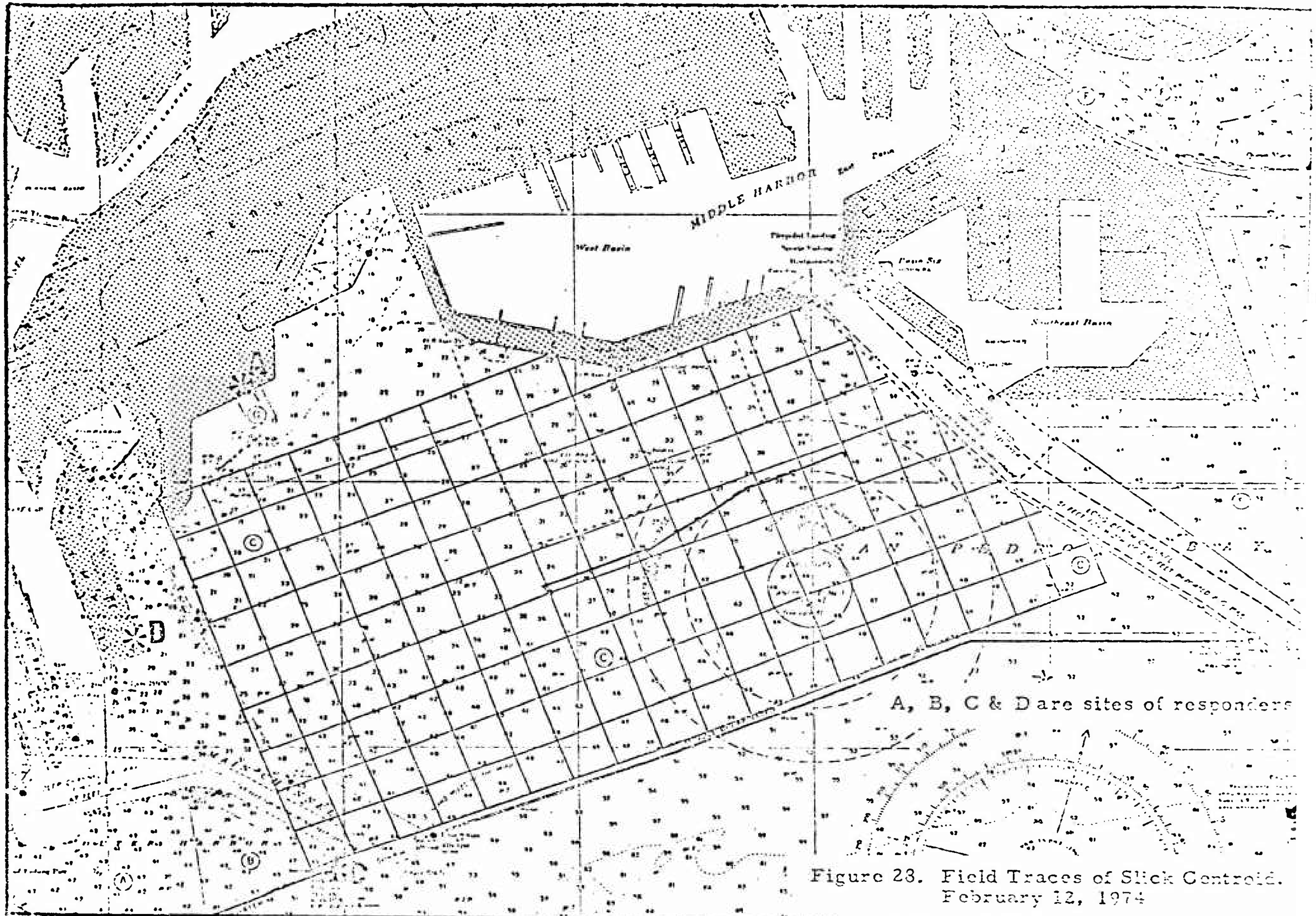


Figure 23. Field Traces of Slick Centroid. February 12, 1974

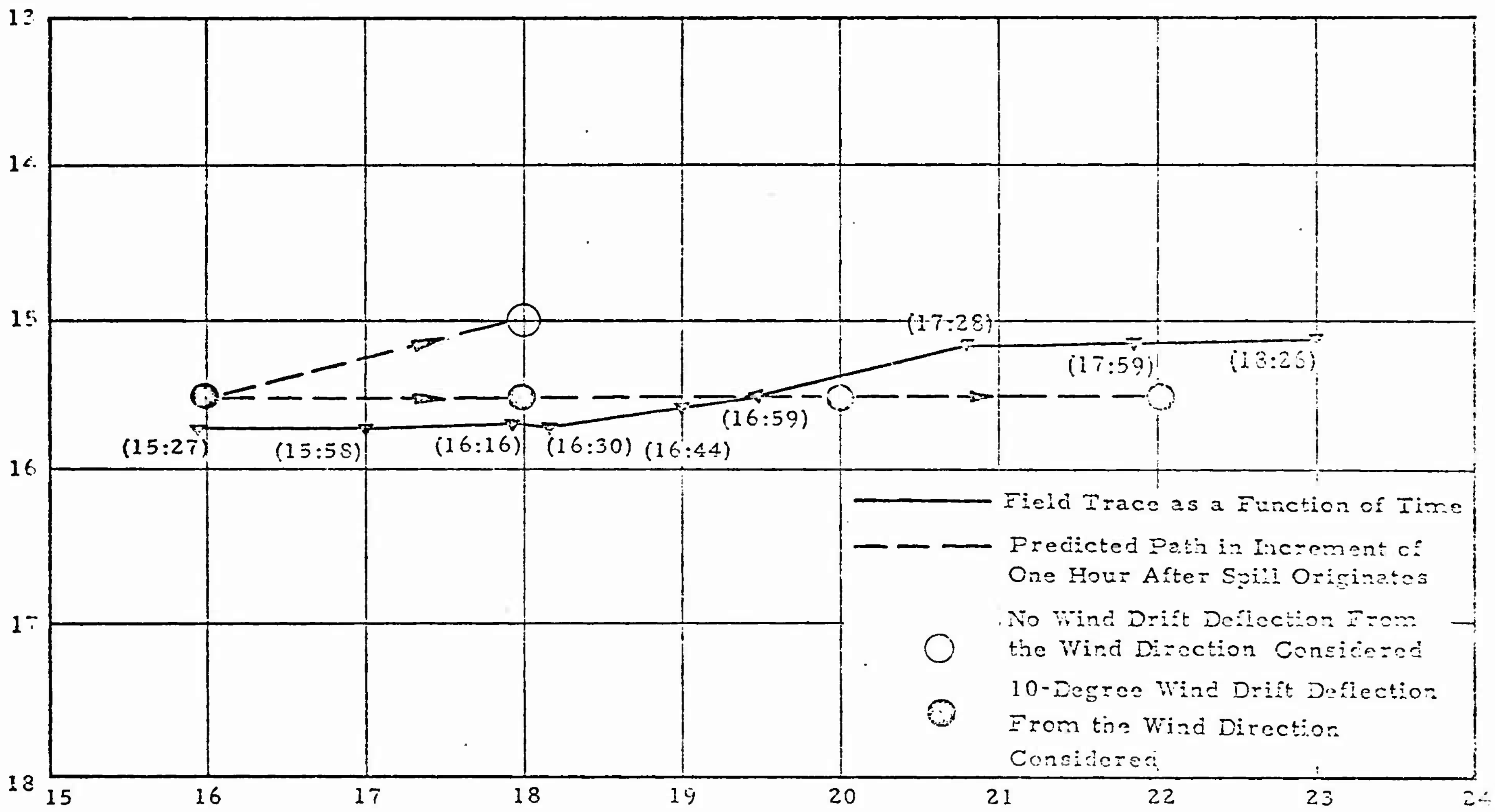


Figure 29. Predicted Path and Field Traces of Slick Centroid - Test 5 - February 12, 1974

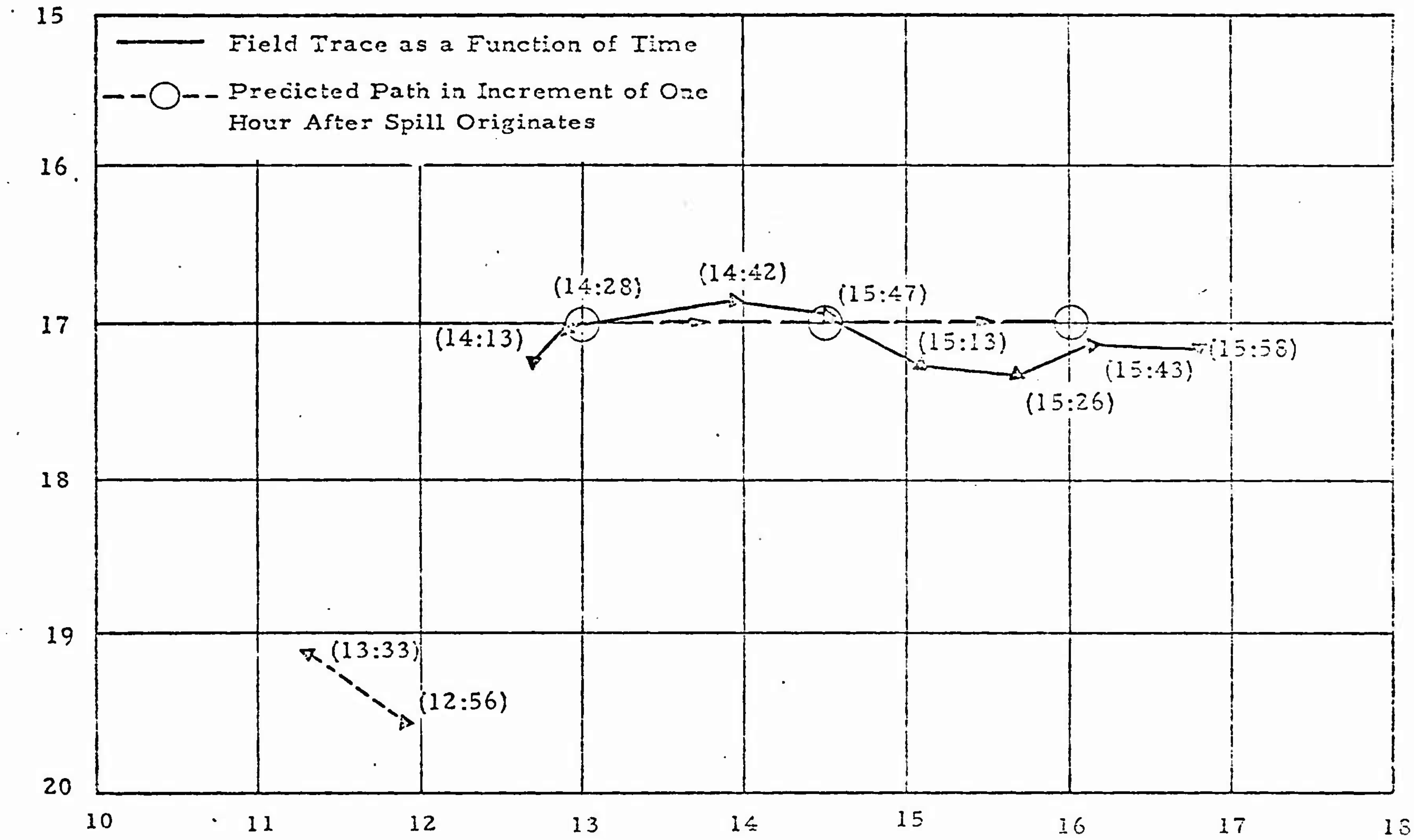


Figure 30. Predicted Path and Field Traces of Slick Centroid - Test 4, Feb. 11, 1974
(10 Degree Wind Drift Deflection Included in Prediction)